Chapter 2

CHANGES IN FOREST USE AND ITS FACTORS

Chapter 2 Introduction

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This chapter examines the influences of human activities on forest utilization at the four study sites. The study period covered 50 to 100 years, depending on the availability of reliable information at each site. This project examined the sustainable use of forests and biodiversity, with the objectives of clarifying the land-use changes at each site, identifying the drivers responsible for these land-use changes, and elucidating the characteristics of these drivers. The study methods included analysis of old maps, aerial photographs, and satellite images to understand the land-use changes. A review of published literature and interviews of relevant persons were also performed to learn more about the drivers responsible for the observed land-use changes.

For Sarawak Malaysia, Ichikawa examines the drivers responsible for the land-use changes using land-use maps from the 1960s to the 1990s. For Sabah, Kitayama et al. analyze the characteristics of land-use changes in the Kinabaru Mountain area and in the Deramakot lowland using satellite images from the 1970s to 2002. Three papers discuss Japan's Yaku Island. In the first, Otani et al. deal with forest-use changes in the western part of the island and in part of the World Heritage Site in the study area. Since this is a main area for their ecological study, this paper provides basic data on the impacts of human activities on the forests of the area. In the second, Sprague et al. perform a GIS analysis of land-use changes along the rim of the island, where human activity has been most intense. In the third, Hirai discusses the role of forests, the benefits they generate, and changes in forest values during six periods from the 17th century until the present. In addition, Miyamoto et al. created maps of land-use changes at Abukuma from 1908 to 1997 using old maps and aerial photographs, and analyzed the background factors responsible for the changes. Finally, Takada et al. describe the possibility of transitions in the land-use changes for the four sites using matrices, and examine methods for the projection of land use under different scenarios.

By comparing the land-use changes at each site, such as the relationship between Japan and Malaysia resulting from the timber trade, land-use changes in each region can be better understood. The results of these analyses of land-use changes provide basic information for the projection of land-use changes under different scenarios and permit the creation of maps of biodiversity, ecological functions, and ecological services in the final chapters.

Land Use Changes during the 1960s–1990s around the Lambir Hills National Park, Sarawak, and Backgrounds to the Changes

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Introduction

In order to examine influences of human-activity impacts on forest biodiversity, this paper clarifies the land use changes during these 40 years and the social and economic backgrounds behind the changes. It also examines the differences between land use changes according to the actors of the land use. The main actors in the study area are: the Iban, a native people of Sarawak, and enterprises and government. The study area is around the Lambir Hills National Park, Sarawak (Figure1) and the area is around 27,000 ha. The area was almost all covered by primary forests around 100 years ago. The question is, how have the forests been converted to today's land uses, which are swidden agricultural fields, secondary forests, mono-crop plantations, and small areas of primary forest?

Methods

The methods of the study are: 1) to read land use from aerial photographs taken in 1963, 1977 and 1997 by colonial and state government and draw land use maps for each year, 2) to calculate the transition of each land use and transition possibility, and 3) to conduct document surveys and interviews on the background to the land use changes with local villagers and governments staff who know about those changes.

Results

Land-use maps:

Figure 2 shows the land-use changes from 1963 to 1997 as a result of reading aerial photographs. The actors who have caused the land-use changes are mainly divided into two. One is the Iban, a native people of Borneo who have lived in the area for a long time and who use forests products and the forests themselves for their subsistence economy. The other is government and corporate actors who have used forests to gain economic benefits on a bigger scale. In figure 2, those areas are shown as "Iban territory" and "state land," respectively.

Matrix and its graphing:

The area of land-use transition and transition possibility from 1963 to 1977, and from 1977 to 1997 are calculated (Table 1) and the result is graphed out (Figure 3). As the next step, the transitions for each area, the Iban territory and state land, are calculated and also graphed out (Figure 4 and 5). Historical trend of the changes in the 2 areas is shown in the figure 6 and 7. From those figures, some trends and characteristics of the land use can be extracted: 1) conversion from primary forest to other land use in the Iban territory started earlier (around 1900) than that in the state land (1960s). The conversion in the Iban territory was mainly for subsistence agriculture, for example for hill and swamp paddy fields. These fields are relatively small (more or less 1 ha) and dispersed, dotted around the Iban territory. 2. The land use in the state land started for commercial logging and large-scale rubber plantation development from the 1960s.

Backgrounds of the land use changes (figure 7): The main land use changes in the Iban territory and the social and economic backgrounds to such changes are: Settlement of the Iban in the study area around 1900, supported by government policies; swidden agriculture in hills and swamps until the 1960s to maintain subsistence economy; expanding area of rubber groves in the 1950s and 1960s after an increase of rubber price in the international market; expanding swamp paddy fields in the 1960s and 1970s as a result of increase in rice demand from logging camps appearing when commercial logging was prosperous, and; value of forest products and fruits as commodities increased in the 1980s and 1990s following the urbanization of Miri city.

The main land-use changes in the state land and those social and economic backgrounds are: rubber plantation development and its failure in the 1960s in the period when rubber price fluctuated in the international market; commercial logging in large areas from the 1960s following increasing demand in the international market; the establishment of the National Park in 1974 when international movements of nature conservation appeared, and; oil palm plantation development after the 1980s when the price increased in the international market.

Conclusion

The land-use changes around the Lambir Hills National Park would be evaluated as below from the viewpoint of biodiversity conservation. In both the Iban territory and state land, a common trend of land use changes is conversion of primary forest into other land uses for economic improvement and development. However, in more detailed observation, the way the changes occur differ between the two types of land. In the Iban territory, the primary forests were mainly converted to small agricultural fields, and those have always been left for fallow and the land returned to secondary forests. The Iban’s lands are seen as a mosaic pattern consisting of small patches of agricultural fields in the large secondary forests. In contrast, in the state land, commercial logging started in the 1960s and large areas became logged forests. After the 1980s, oil palm plantation development in large scale started around the study area. In conclusion, in state land, large scale developments have been brought about in a relatively short period, which seriously affects biodiversity conservation, while the land use of the Iban territory is characterized as relatively slow change in small scale in individual patches of agricultural fields. However, if the national park had not been established, the primary forest in it would have been logged by enterprises and also by the Iban. The roles of both the native’s land use and government policies are important for biodiversity conservation.

Reference

Ichikawa, M. (2007) Degradation and loss of forest land and land use changes in Sarawak, East Malaysia: a study of native land use by the Iban. *Ecological Research* 22. 403-413.

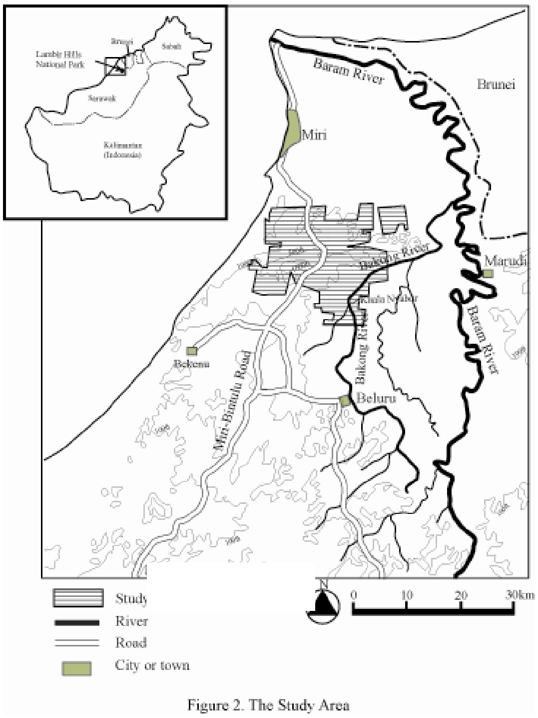
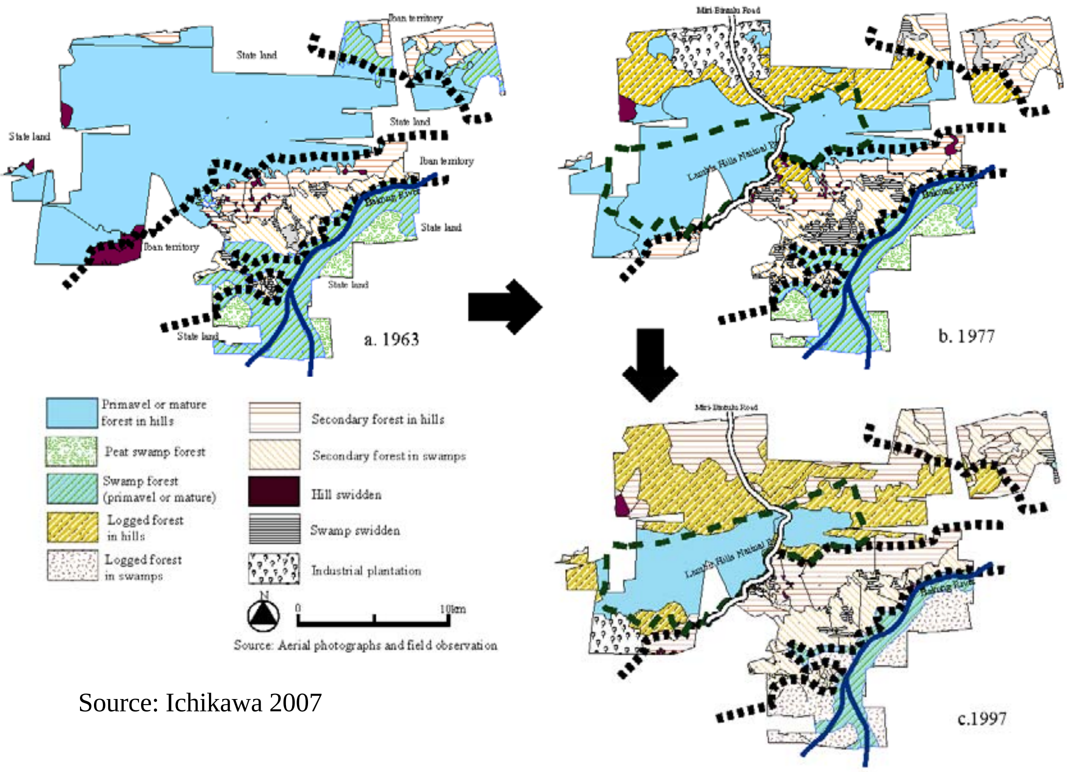


Figure 1 The study area



Source: Ichikawa 2007

Figure 2 Land use maps in each year

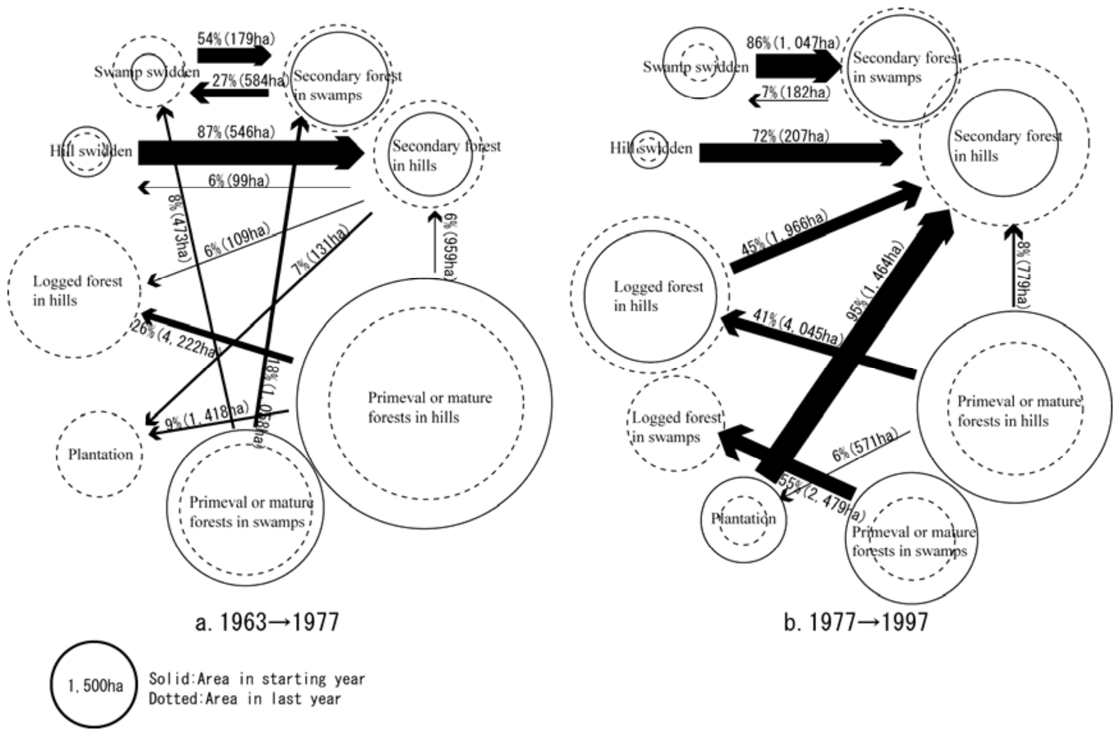
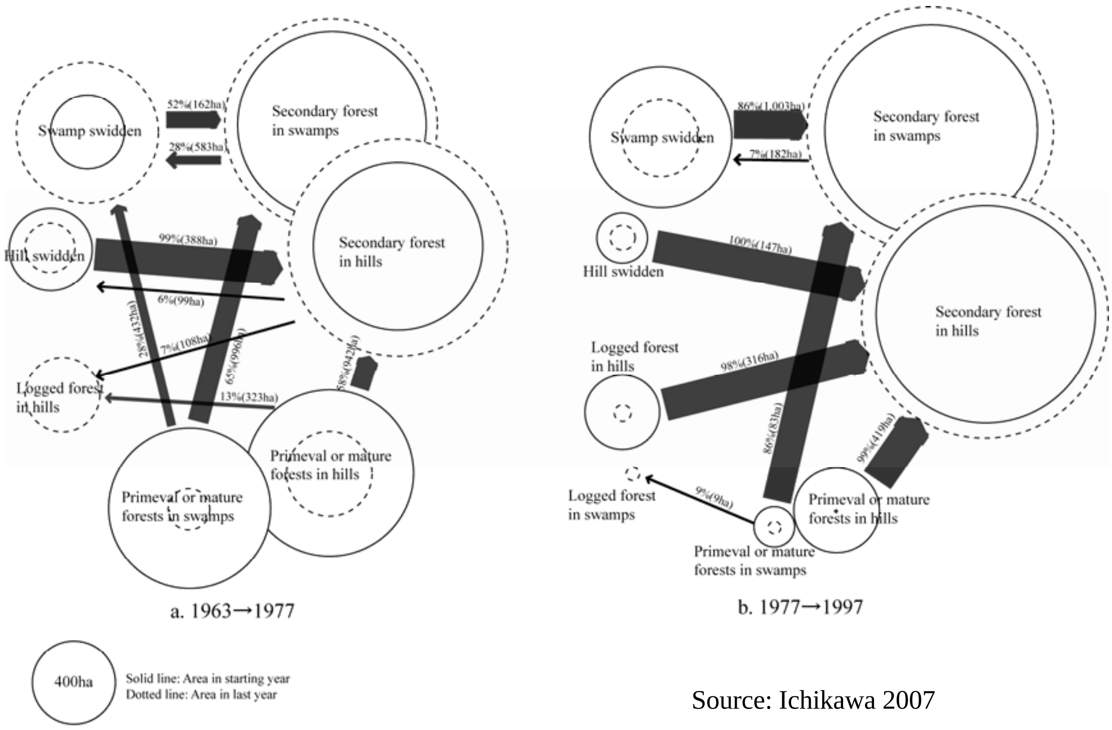


Figure 3 Land use changes in whole study area, 1963 to 1977, and 1977 to 1997



Source: Ichikawa 2007

Figure 4 Land use changes in the Iban territory, 1963 to 1977, and 1977 to 1997

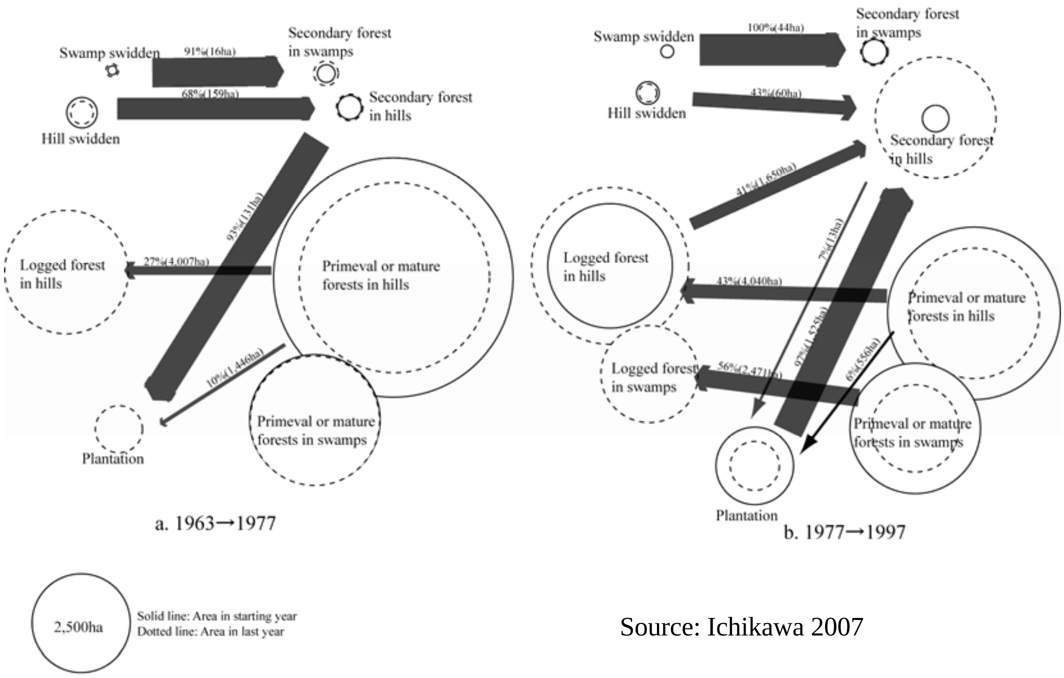


Figure 5 Land use changes in the state land, 1963 to 1977, and 1977 to 1997

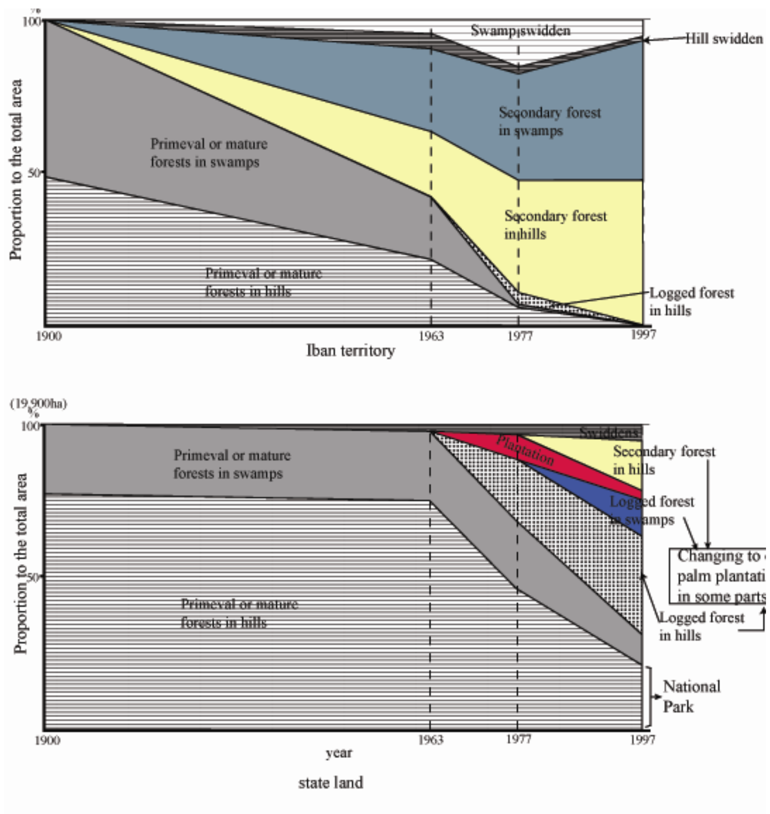


Figure 6 Characteristics of land use changes in the Iban territory and the state land
Source: Ichikawa 2007

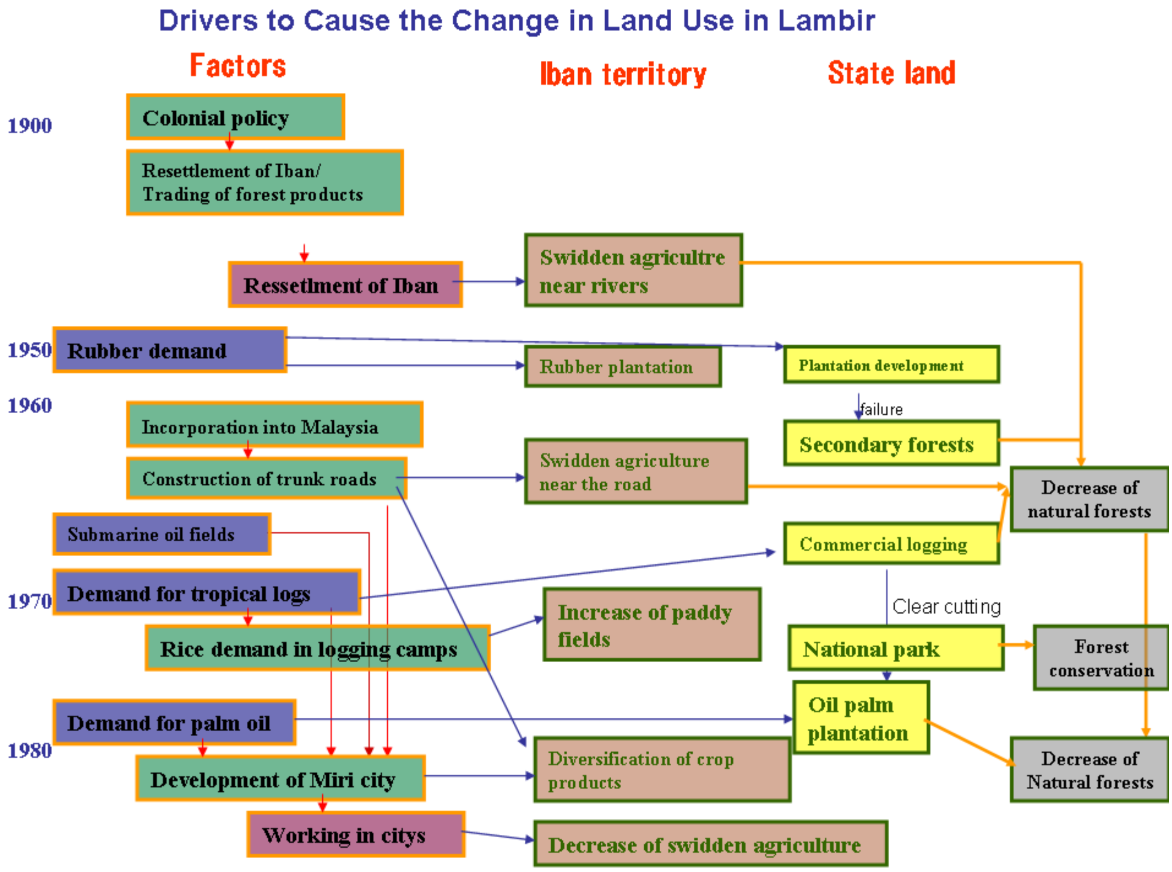


Figure 7 Background of land use changes

Modern Land-use Changes in the Upland and the Lowland Terrains of Sabah, Malaysia, and their Causal Interpretation

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Introduction

The conversion of tropical rain forests has been wide-spread and rapid in Southeast Asia (Sodhi and Brook 2006). Presently, this region demonstrates the highest rate of the loss of tropical rain forests (Laurance 1999). Approximately, 1.5 million ha of tropical forests were converted annually from the major four islands of Indonesia (Sumatra, Borneo, Sulawesi and Irian Jaya) (Sodhi and Brook 2006). For the entire world, Laurance (1999) estimated that 15.4 million ha was destroyed annually between 1980 and 1990 based on the FAO data on forest cover; the same author also suggested that additionally 5.6 million ha was degraded. These numbers are based on broad categories of land cover types over large areas. Achard et al. (2002) argued that the rate of forest loss in the world tropics was much lower (5.8 million ha per year), using satellite data, than previously believed.

This kind of controversy may arise from several factors. We suggest that one of such factors is related to the resolution of analysis in terms of time and space. The rate of progressive, secondary succession such as the one in old fields or in selectively logged forests can be quite fast in the tropics. If one analyzes the land-use changes in which vegetation recovery is involved, over an extended period longer than the recovery process, the analysis will result in an underestimate of forest conversion. In addition, land conversion can often take place in a smaller spatial extent than 1ha (100 x 100m) on the ground, in which case the conversion cannot be adequately detected by a large-scale analysis that commonly uses a larger mesh size than several km. Mismatch of spatial resolution may under- or over-estimate the area of forest conversion.

The spatial scale of land-use changes is intimately related to their drivers. Land use for subsistence farming may be small in scale, while the land use caused by large-scale socio-economic drivers at regional to international levels can be quite extensive. The changes of any given landscape in Southeast Asian tropical rain forests are actually driven by several different drivers. Contemporary landscapes must demonstrate a complex pattern of small-scale land cover types intermixed with large-scale land cover types. Therefore, we analyzed the spatio-temporal patterns of land use in contemporary Sabah, Malaysia, with the use of Landsat data (resolution of 30x30 m), so that we can analyze the land-use patterns of subsistence farming as well as of large-scale developments.

Although the drivers of land use are the same, the type of land cover and the consequences (e.g. spatial patterns) can be quite different if physical environments are different. For instance, for the same driver (i.e.

the demand for cash and cash crop), farmers will choose the crop that yields the best return for an investment in each environmental setting. The sate of Sabah is mountainous and environmental setting is contrasting between upland and lowland. Therefore, we hypothesize that the same driver will result in different types of land cover and consequences in the upland versus the lowland. We compare the land-use type and patterns between the two climate zones.

Materials & Methods

Land-use and modern history of the study areas

The state of Sabah is located in the northernmost part of Borneo and presents mountainous upland to undulating low-lying terrains. The mountainous topography culminates on Mount Kinabalu and a typical undulating low-lying terrain is found in the Deramakot area.

Kinabalu: The summit of Mount Kinabalu (4,095m, 6N 116E) and its surrounding area was first gazetted as the Kinabalu National Park in 1964. Originally, the purpose of gazetting the area was to preserve the mountain as a permanent war memorial. Later, park boundaries were modified and it was re- gazetted as Kinabalu Park with a total area of 73,500 ha in 1984. In 2000, the entire park was designated as a World Natural Heritage site because the continuum of pristine vegetation from the lowland to the summit together with its high biological diversity was recognized as a common human heritage. The vegetation consists of mixed dipterocarp lowland tropical rain forests up to 1200 m, montane tropical rain forests up to 2700 m, subalpine forests up to 3400 m and alpine vegetation up to the summit. Park Headquarters are located at 1560 m asl and serve as the base for mountain climbers and tourists. Mean annual air temperature at the Park Headquarters is 18.3℃ with mean annual rainfall of 2380mm between 1996 and 1997 (Kitayama et al. 1999).

The majority of the area within the park is pristine with only 6.56% of the total area being substituted by man as of 1986 (Kitayama 1991). No permanent farming and little encroachment within the park are recognized as of 2007. However, the surrounding areas are heavily used by man. Particularly, the southeastern upland plateau (Mesilau Plateau) in the elevation range of 800 to 1600 m are now used for intensive agriculture (mostly temperate-vegetable growing), large-scale dairy farming, golf course, and etc. The southern to western slopes are mostly used for subsistence agriculture and shifting cultivation. Logging activities were once rigorous in the eastern and the northern areas, but now subsided. Noteworthy is the cupper mining which began in 1970 and was recently shut down. A total area of 2,555 ha was removed as the mining area from the national park in 1970 and it produced 15,000 tons of ore daily at its full operation.

The land conversion by modern agriculture around Mount Kinabalu began probably as early as 1958 when a jeep track connected the Park Headquarters with the capital city of Kota Kinabalu. By 1960, there were 8 ha of land under vegetable cultivation. The jeep track was not enough to support a fuller production of temperate vegetables and production rate did not increase drastically. In 1971, a total area of 162 ha was under “cabbage ladang” which means temperate vegetables cultivated in shifting cultivation system. The agricultural production drastically changed after 1982 when a sealed highway connected Mount Kinabalu with Kota Kinabalu. Fig. 1 depicts the change in the number of visitors to Kinabalu Park. The number drastically increased after the highway was completed. Better transportation changed attitude of farmers from “cabbage ladang” to permanent terrace farming, and triggered systematic land conversions.

Deramakot: Deramakot Forest Reserve (5N 117E) is part of Sabah’s 2,674,570-ha Class II Commercial Forest Reserves, which are meant to conserve forest for commercial timber production. Deramakot Forest Reserve consists of one forestry management unit of 55,149 ha and is situated at the upper Kinabatangan River. The climate is humid equatorial with a mean annual temperature of about 26℃ with a mean annual rainfall of approximately 3,500 mm. The elevation ranges from 100 to 300m and the entire area represents a lowland undulating terrain. The entire area is covered with mixed dipterocarp lowland tropical rain forests.

Commercial logging started in Deramakot in 1956 (Huth and Ditzer 2001). The initially adopted logging method was the Malayan Uniform System (MUS), which allowed harvesting all commercial timber trees over 45 cm in diameter at breast height (DBH). In 1971, the Sabah Uniform System (SUM) was newly introduced following the timber boom in the late 1960s. This method employed heavy machinery for harvesting, skidding and transportation without appropriate consideration for forest stand and site condition (Kleine and Heuvedlop 1993). The area was licensed for logging from 1955 to 1989. The minimum diameter for harvesting was 60 cm and the felling cycle was 60 years. The majority of the Deramakot area was probably affected mildly to heavily by this logging system. Variable cutting intensities of past management practices resulted in an extremely heterogeneous condition of the residual forests (Lagan et al. 2007). Only 20 % of the area was considered well stocked with harvesting trees and more than 30% was covered by very poor forest with virtually no mature growing stock left. The demise of timber resources in Deramakot might have followed the same track of economic downfall of Sabah (Fig. 2). The state annual revenue from forestry and forest-related industries peaked in 1988 with an approximate amount of 1,100 million ringgits, but sharply dropped since then. This triggered the reform of Sabah’s old forestry system into a new sustainable forestry system (Ong and Sinajin 2003).

For the period 1989–2000, the Sabah Forestry Department, in collaboration with the German Technical Agency implemented the Malaysian-German Sustainable Forest Management Project, and Deramakot Forest Reserve was chosen in 1989 as the project site. The project was made up of four phases (Lagan et al. in press): 1) a strong research emphasis with a component for management planning (1989–1992), 2) management planning, training and consolidation (1992–1994), 3) institution building, human resource and development, consolidation/ implementation and extension (1995–1998), and 4) consolidation, planning and human resource development (1999–2000). Deramakot Forest Reserve was certified as “well managed” by an international certification body, the Forest Stewardship Council (FSC), in 1997. It is the first natural forest reserve in Southeast Asia managed in accordance with sustainable forestry principles.

Deramakot Forest Reserve is now divided into 134 compartments, a smallest operational unit where annual timber production takes place. Sabah Forestry Department harvests timber at a rate of two compartments per year, with an intention of 67 years of recovery time before the next harvest takes place.

For the details of the guidelines currently adopted in the Deramakot Forest Reserve, see Sabah Forestry Department (2000).

Adjacent to the western border of Deramakot Forest Reserve lies Tangkulap Forest Reserve where until recently conventional intensive logging was continuously applied by a private sector. Therefore, compared with Deramakot training area, Tangkulap Forest Reserve represents more dynamic timber harvest and the rapid reduction in forested area. There are no statistical data available for the amount or the rate of past timber harvest in the Tangkulap area.

To the north of Deramakot and Tangkulap is located a vast area of oil palm fields. The development of oil palm plantation involves large-scale mechanical removal of above-ground vegetation and the establishment of the monoculture of single oil palm. However, land conversion in this area in recent years has been less dynamic, as fruits only are collected if once developed, although the development of oil palm fields still occurs in marginal areas. Replanting of juvenile oil palm trees also takes place in the senescent fields.

Methods

The following nine data of Landsat imagery of Multi-Spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper plus (ETM$^+$) were acquired in time series for classifying land cover and use types from the archives of Tropical Rain Forest Information Center (TRFIC) (http://www.bsrsi.msu.edu/trfic/index.html) and from Earth Resource Observing System (EROS) data gateway of USGS (http://edc.usgs.gov/products/satellite.html):

Kinabalu	January 12th, 1973, Landsat MSS; June 29th, 1985, Landsat MSS; June 14th, 1991, Landsat TM; Oct 22nd, 1999, Landsat ETM$^+$; May 19th, 2002, Landsat ETM$^+$
Deramakot	August 25th, 1985, Landsat MSS; May 22nd , 1991, Landsat TM Sept. 9th, 1999, Landsat ETM$^+$; May 28th, 2002, Landsat ETM$^+$

Radiometric and geometric correction were applied to these Landsat data before analyzing them in time series to eliminate some errors commonly produced during data acquisition (see Darmawan 2004 for the details). Land cover and use types were categorized based on supervised classification with maximum likelihood method. In the first stage, unsupervised classification was applied to each date of Landsat data with the fuzzy C mean and K mean method for selecting training area. By evaluating dendrogram and co-occurrence, about 50 classes of land cover types were analyzed and regrouped into a fewer number of classes. Land cover type was assigned to each of the classes based on ground truth and spectral patterns. Subsequently, the tasseled cap transformation was used to develop the temporal pattern of land cover and use types in each of the two areas (see Darmawan 2004 for the details).

We attempted to link the land-use change with the change of the taxonomic diversity of canopy trees based on the relationships between above-ground biomass and the taxonomic diversity of canopy trees. As the satellite data of the Kinabalu area are often noisy due to haze and clouds, we used the data of Deramakot only. Because there is an inherent problem that normalized indexes using spectral reflectance saturate at higher biomass (Nakazono et al. submitted), we employed the biomass values that were estimated with a special algorithm by Nakazono et al. (submitted) and Kitayama et al. (2006). First, we regressed the number of canopy-tree taxa per 0.2 ha at species, genus and family level with actually measured biomass values using the census data of Seino et al. (2006) (N=10). The number of families yielded the highest correlation coefficient (r^2=0.552; P=0.014). Therefore, we used the number of families per 0.2ha as dependent variable. We extrapolated this regression model to the entire Deramakot area using the biomass values estimated by Nakazono et al. (submitted) and Kitayama et al. (2006) for 1985 and 2002. We arbitrary assigned the value 1 to oil palm plantations. Subsequently, we calculated frequency distribution of canopy diversity classes.

Results

Land use types changed drastically in both areas through time (Figs. 3 and 4). In the Kinabalu area, the most drastic change was the rapid increase of agricultural and bare lands between 1973 and 1991. In 1991, patches of agricultural and bare lands occurred in the southeast and southwest slopes. In 1973, the most wide-spread cover type in the Kinabalu area was secondary forests, which decreased in area later (Fig. 5). After 1991, shrub land and rangeland increased drastically. The area of “pristine forests” temporary increased in 1991, probably due to the re-growth of secondary forests.

In the Deramakot area, land-use changes were also dynamic and rapid (Fig. 4). Most obvious change was the steady increase of oil palm plantations. The development of oil palm plantations is massive but not patchy unlike the agricultural development in the Kinabalu area. Oil palm plantation expanded in area steadily after 1985 (Fig. 6). On the other hand, the area of pristine forests decreased successively from 1985 to 2002 (Figs. 4 and 6). The reduction of pristine forests from 1991 to 2002 occurred as the disappearance of the remnant forests which were interspersed among selectively logged production forests. Some areas that were recognized as bare or sparse vegetation interspersed in the logged-over forests in 1991 recovered to secondary forests, probably reflecting the protection from severe logging. A new land cover category “other agriculture” appeared in 2002; however, we could not confirm the actual land use of this category on the ground.

The frequency distribution of species richness (indexed by the number of families per 0.2ha) changed considerably from 1985 to 2002 because the above-ground biomass of the vegetation changed between the two years (Fig. 7). The mode of the richness occurred at 27-28 families per 0.2 ha in 1985. It became 23-24 families per 0.2 ha in 2002. The frequency of the mono-culture with reduced canopy diversity increased in 2002.

Discussions

Both areas (Kinabalu and Deramakot) demonstrated rapid and dynamic changes in land use. However, land-use type and spatial pattern (patchiness and extension) differed much between the areas.

On Kinabalu, small patches of agricultural lands occurred in the southeast and southwest slopes and surrounded the park boundaries in 1991. Most of these patches corresponded with the intensive agriculture employing terracing and with sporadic shifting cultivations. This contrasts with the occurrence of sparse shrubby vegetation in 1973, the time when traditional shifting cultivation was more widespread. Although our time resolution is coarse (i.e. 1973, 1991 and 2002 only in time series), the increase of intensive agriculture fields is likely to correspond with the development of the sealed highway that connects the Kinabalu area with Kota Kinabalu in 1982. The development of the highway improved the transportation ability of harvested temperate vegetables to the coastal town and contributed to the cash yield of local farmers. This might have triggered the expansion of intensive-agricultural land to the interior.

Although intensive, farmers frequently lay land fallow in their terrace system. During fallow time, pioneer trees such as *Trema orientalis* form a shrub land in three years (Ohtsuka 1999). Such fallow system and fast secondary succession in this area form a dynamic land-cover system of retrogressive and progressive successions. Cool upland climate is a prerequisite for the formation of such a system because temperate vegetable is grown only in this upland area. Secondly, small-scale tenant farming is still the major faming method here and hence the patchy land-uses occur throughout the area.

The existence of the protected area (Kinabalu Park) must have indirectly influenced the land use of the surrounding non-protected area. As the passage of the highway was completed and the number of climbers rapidly increased, more local people were engaged as the park staff or in the tourism industry, bringing capital to the local village for further development. Thus, the mountainous topography, cool climate and the passage of the highway provided the basis for both protection and development forming a dynamic land-use system in the Kinabalu area. In contrast to the Indonesian state of Kalimantan, where the area of protected areas declined by more than 56% (Curran et al. 2004), we did not find any trace of encroachment into the park.

In the lowland Deramakot area, selective logging and the development of large-scale oil-palm plantations are the driving force of the land-use changes. The original vegetation of the entire area of Deramakot must have been mixed dipterocarp lowland tropical rain forests. The pristine forests that have consistently retained high stocks from 1985 to 2002 are recognized in the west mountainous area and the southwest area as of 2002 by dark green color in Fig. 4. More than one half area of this region had been heavily affected by selective logging by 1985 as indicated by light green color in Fig. 4. By 1991, many stands of the selectively logged forests had obviously recovered in stock by 1991 as patches of dark green color occurred. Therefore, the Deramakot area again represents a dynamic landscape with selective logging and fast secondary successions.

The area of oil palm plantations increased rapidly between 1985 and 1991; the timing of the rapid expansion appears to correspond with either or both the downfall of logging industry or/and the increased commodity price of palm oil products. Between 1991 and 2002, the area of oil palm plantations was extended into the south towards Deramakot Forest Reserve. It is an interesting subject as to how the capital for the oil palm development has been collected, but it is beyond the scope of our paper. Because the Class II Commercial Forest Reserves (Deramakot is one of them) are the designated areas by law with boundaries, the oil palm plantations will not proceed to the south anymore.

The frequency diagram of the family numbers of canopy trees demonstrated impoverished diversity in 2002. Although our assumption is based on a simple regression between above-ground biomass and family number, the depicted pattern reflects a generally impoverished trend of diversity due to harvest and land conversions. The expansion of oil palm plantations will further lead to the increase of monoculture stands. Our estimate depicts a crude spatiotemporal pattern only and it is not known what are the biological consequences of reduced diversity.

Overall, our analysis demonstrated dynamic land-use changes in two tropical rain forest areas. Both areas simultaneously demonstrated progressive and retrogressive successions in a range of patch scales. The simultaneous occurrence of progressive and retrogressive changes was detected because we employed satellite data of relatively-high resolution (30x30 m) in a time series. This type of dynamism would not have been elucidated if we employ coarse-scale data (e.g. 1x1 km) that are conventionally used for processes at global scales.

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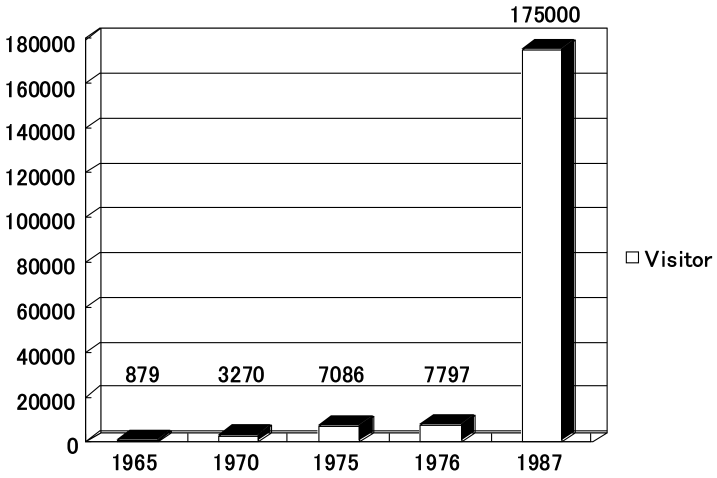

Fig. 1 The number of visitors to Kinabalu Park through time.
Data based on the unpublished statistical data of the Sabah Parks.

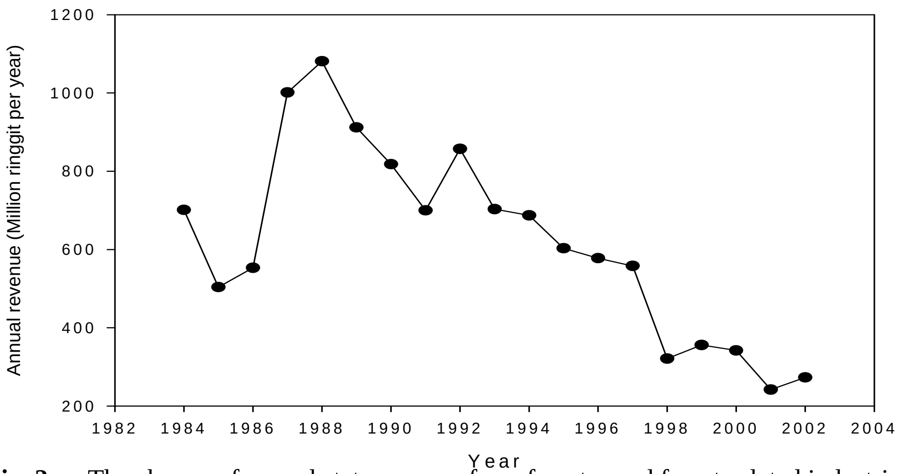

Fig. 2 The change of annual state revenue from forestry and forest-related industries in Sabah
Data after Sabah Forestry Department (2002).

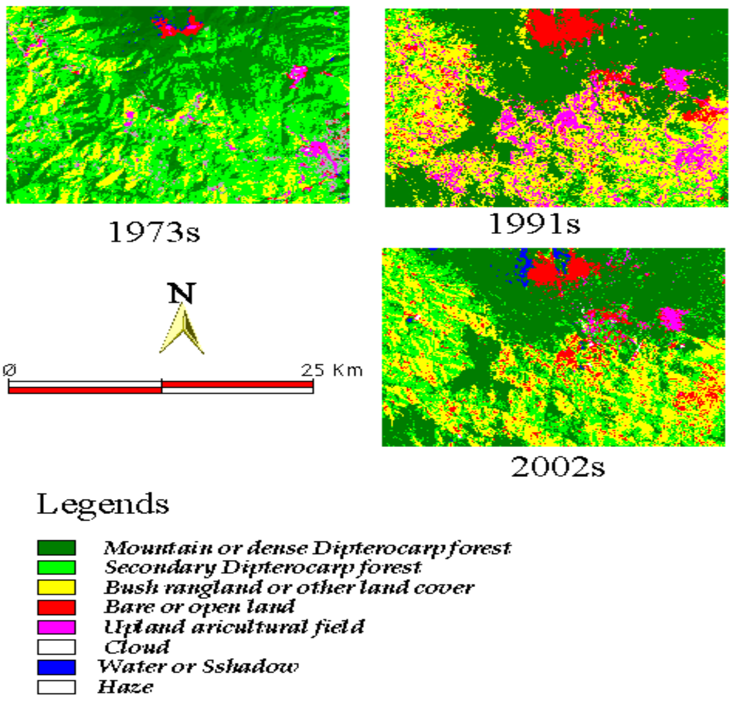

Fig. 3 Land cover changes in the Kinabalu area from 1973 to 2002.

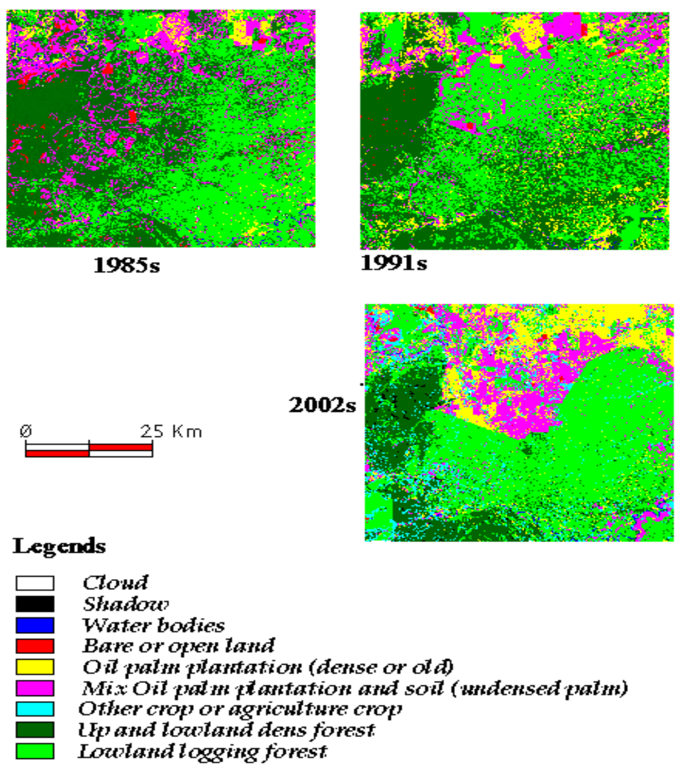

Fig. 4 Land cover change in the Deramakot area from 1985 to 2002.

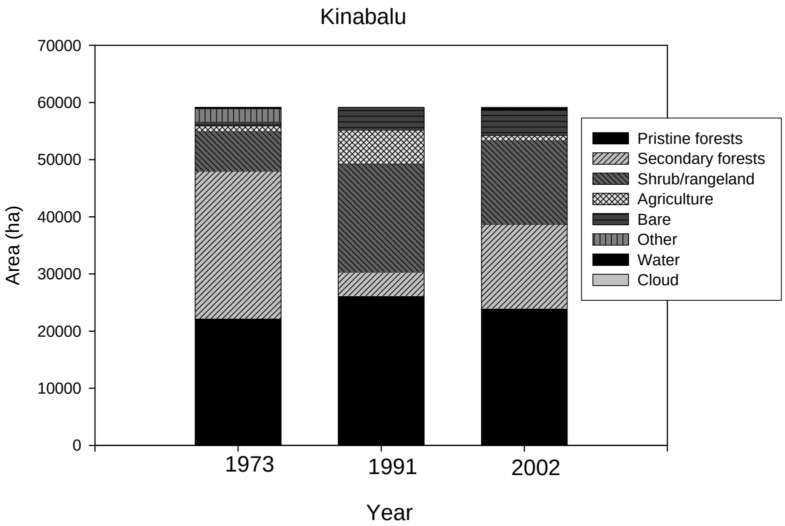

Fig. 5 The change in the relative area of land cover categories in the Kinabalu area from 1973 to 2002.

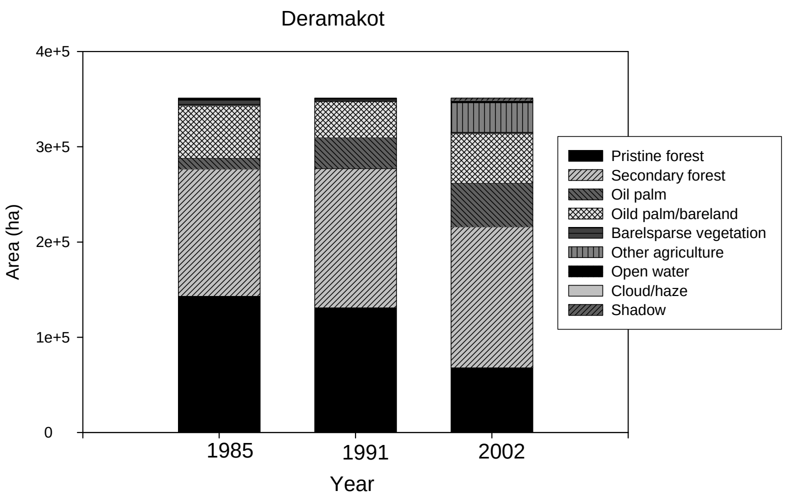

Fig. 6 The change in the relative area of land cover categories in the Deramakot area from 1985 to 2002.

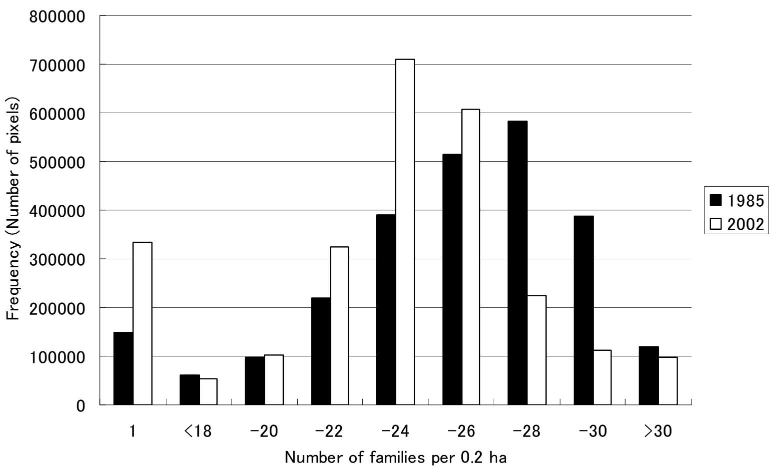

Fig. 7 The frequency distribution of the number of the families of canopy trees per 0.2 ha in year 1985 and 2002. Frequency indicates the number of pixels that fallen to each of diversity classes (the number of canopy trees per 0.2 ha).

History of Forest Utilization in the World Natural Heritage Area of Western Yakushima Island

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Introduction

The western lowland of Yakushima Island, the World Natural Heritage area, is covered by broad-leaved evergreen forest subjected human disturbance, such as cultivation, wood charcoal production, and camphor distillation. However, details of the forest utilization remain unclear, because most of this area was owned privately prior to 2005 with no available records for land use. Comprehension of the human impact in the past, as well as biological and ecological studies, is required for understanding the current condition of the forest and to develop an effective conservation scheme. We conducted field research and literature surveys, including interviews with local people, in order to review the history of forest utilization in the western lowland area of Yakushima Island.

Materials & Methods

The study area was located in the Han-yama and Kawahara sites in the western lowland of Yakushima Island (ranging from 0 to 300 m in altitude, and covering approximately 1 × 4 km; Fig.1). There are no settlements within the study area except a single road traversing it. Approximately, a 200-m contour line was considered a boundary for the land management: government-owned forest at the upper side, and Kagoshima prefecture-owned forest at the lower side. The latter was privately owned prior to 2005.

We referred to some documents, old maps, and aerial photographs taken in 1947 and 1969. The aerial photographs were subjected to orthometric correction using ERDAS Imagine ver.8.7, and logged sites in the photographs were surveyed with ArcGIS ver.9.

From March to August 2006, we located abandoned artificial structures, such as charcoal kilns and farm fields with stone masonry using a GPS receiver (MobileMapper Pro, Thales Navigation Inc.). Size and characteristic features of charcoal kilns were also recorded.

In order to date the period of human activities such as charcoal production and camphor distillation, we extracted tree-ring cores using an increment borer, and determined tree ages by counting tree rings under a stereoscopic microscope. For the charcoal production, we determined the tree ages of *Melia azedarach* var. *subtripinnata* standing adjacent to abandoned charcoal kilns to estimate the year of abandonment of the kilns. For the camphor distillation, we determined the ages of *Cinnamomum camphora* trees, the raw material of camphor.

Results

In the Han-yama and Kawahara sites, a total of 37 abandoned charcoal kilns were found (Fig.2). Most of the kilns were located in concaved sites and had an oval or clam shell-shaped bottom. The horizontal and vertical inner widths ranged from 3.1 to 5.1m and 2.4 to 4.1m, respectively. Many artificially squared plots with stone masonry surrounds were recorded, mainly on gentle slopes in Han-yama and Kawahara (Fig. 2).

In total, seven *M. azedarach* var. *subtripinnata* trees were estimated at ages ranging from 44 to 86 years old, suggesting the approximate abandonment years of 1920 to 1962 for seven of the charcoal kilns (Fig. 2). The ages of 12 camphor trees in three sites of Kawahara (Fig. 2) averaged 70 years, ranging from 58 to 86 years, indicating the establishment year of around 1936 for the camphor trees in Kawahara.

From the aerial photographs taken in 1947, logged areas totaling 50.3 ha were identified, and 32.2 ha of them appeared to have been clear-felled in the period near to 1947 (Fig. 3). Areas of 44.8 ha were seen from the aerial photographs of 1969 to experience logging between 1947 and 1969 (Fig. 3). These photographs also showed bare ground (1.5 ha) due to waste soil associated with road construction in 1967. The location of houses and farm fields recorded by GPS usually fell into the clear-cut areas identified from the photographs of 1947.

Discussion

Here, we describe the history of forest utilization in the study area, taking events in chronological order. The Kamiyaku-town Local History Editing Committee (1984) stated that the area stretching from Nagata to Segire (Fig. 1) had been managed by Nagata village since early times. There is, however, no description of a village in the western part of the island on an old map drawn in 1882 (unknown publisher 1882) or a 1/200,000 geographical map drawn in 1889 (Land Survey Division 1892). Nishiwada (1894) listed the names of villages in Yakushima Island; however, the three villages, Han-yama, Kawahara, and Segire, were not included. On the other hand, we were able to find descriptions of Han-yama, Kawahara, and Segire, with symbols of accommodation units, on geographical maps drawn in 1921 (Land Survey Division 1923). Furthermore, the operation plan for the national forest (Kagoshima Regional Forest Office 1922) contained a description “Segire, farmers, three families.” The tree-ring analysis suggested that two charcoal kilns in the northern Kawahara area were abandoned in 1920 and 1921 at the latest (Fig. 2), suggesting human activities before this time. Yaku-town Local History Editing Committee (1993) said that Mr. Y. Kitazono from Kurio village (Fig. 1) had produced camphor at Kawahara in 1914–1915. According to the Monopoly Bureau (1942), at least several people were needed to work for the raw procurement and kiln management, and to stay over near to a camphor factory. For the reasons mentioned above, people appear to have first colonized these sites around 1900 to undertake cultivation, wood charcoal production, and camphor distillation.

From the tree-ring analysis of 12 camphor trees in the Kawahara site, these trees seemed to have been established around 1936, suggesting logging for camphor trees until this point of time. As mentioned earlier, we were only able to obtain information for camphor production in Kawahara for 1914-1915, and there is a time discrepancy of approximately 20 years between the documentary information and the tree ages. Yaku-town Local History Editing Committee (1993, 1995, 2003) said that camphor production had been an active form of industry in Yakushima Island in the 1920s and 1930s, and that camphor factories in Nakama village (Fig. 1) had obtained raw materials from various sites, including Ohko near to Segire. Camphor trees in Kawahara may have been felled around the 1920s and 1930s for factories in remote areas, such as Nagata and Kurio.

Dr. J. Miyamoto, a folklorist who visited Yakushima Island in 1940, described the situation as follows, “Kawahara village is deserted now, and Han-yama village is almost abandoned with a few farmers (Miyamoto 1974).” We could not find any information on the status of Segire village at that time. In the period around 1940, it seems that few activities were conducted in connection with charcoal production and camphor distillation in the study area.

We obtained information from local people about logging at Kawahara for military purposes in the early 1940s, during World War 2. The information gleaned was as follows: Mr. D. Hidaka from Nagata worked as a punch marker for logs; a Korean group of 50–60 or even 70–80 loggers lodged in Kawahara; and Mr. Kim, a 75-years-old Korean, received a letter in 1942 from his father who was working at Kawahara (Nishinihon news-paper, 2006.08.06). Logging at Kawahara in the early 1940s must be a fact, although there is no available documentation telling of this activity. Logging for military purposes in the early 1940s presumably caused the large-scale deforested areas in the Kawahara site found in the aerial photographs of 1947 (Fig. 3).

In the late 1940s, people lived in Han-yama for sweet-potato cultivation and charcoal production (Ankei & Ankei 2000). At that time, the “Satsuma method,” promoted by Kagoshima prefecture, was employed widely in Yakushima Island (Uchida 1952, Kamiyaku-town Local History Editing Committee 1984, Yaku-town Local History Editing Committee 1993, 2003). Some abandoned charcoal kilns found in the study area had distinguishable features that accorded with the Satsuma method kiln, such as the clam shell bottom shape and one exhaust port on the back side. Using a Satsuma method kiln could produce approximately 1,750kg of charcoal (70 strew bags) twice a month (Yaku-town Local History Editing Committee 2003). Yield percentage was reported at approximately 20% for this method (Kagoshima Foresters Association 1925, Uchida 1952), so that 8 to 9 t of raw wood was needed for one charcoal burning. According to the above-ground biomass data recorded at the research plot located in the upper side of Han-yama (Forestry and Forest Products Research Institute, http://fddb.ffpri-108.affrc.go.jp/index.html), the forest contained approximately 103 t/ha biomass of tree species for good charcoal such as *Pinus thunbergii*, *P. densiflora*, *Quercus phillyraeoides*, *Q. salicina*, *Castanopsis sieboldii*, *Lithocarpus edulis*, *Rhaphiolepis indica* var. *umbellate*, *Rhus javanica* var. *roxburghii*, *R. succedanea*, and *Distylium racemosum*. Assuming the continuous running of a charcoal kiln, a 4-ha of raw material would seem to have been depleted over 2 years. Some charcoal kilns were located as close as approximately 100m apart from each other in the study area (Fig. 2), because of which charcoal makers may have built a new kiln every few years.

Meisei Timber, a civil corporation, purchased the private land in the western lowland of Yakushima Island from Shinwa Timber in 1951. According to someone who worked as a field overseer, Meisei Timber conducted intensive logging for wood pulp mainly in the Segire site, and cut down trees of the two species *Cryptomeria japonica* and *P. armandii* var. *amamiana* in Kawahara. Matsuda (1997) suggested that the forest in the Han-yama area also experienced logging by Meisei Timber in around 1955. Logged areas shown in the aerial photographs of 1969 (Fig. 3) are additional indications of the accuracy of information about pulp logging. From the scattered distribution of abandoned charcoal kilns in the gaps of logged areas shown in aerial photos, it was deduced that almost the entire area of the Han-yama and Kawahara sites experienced logging of varying intensity for charcoal and wood pulp between the 1940s and the end of the 1950s. The logging operations of Meisei Timber continued in the Segire site until around 1965 (Ohyama 2006).

In 1958, only Mr. & Ms. Tanaka lived in Han-yama, and they stayed there until around 1965 for potato cultivation and mushroom growing, as well as fuel wood gathering. However, someone was conducting charcoal production and rosin collection in Han-yama between 1960 and 1964 (Ankei & Ankei 2000). The evidence of resin collection was backed by fallen trees with V-shaped scars in Han-yama and Kawahara. There are no records of dwellers in the western lowland of Yakushima Island after 1965, except for around the Nagata lighthouse. Other than for the road construction in 1967, the Han-yama and Kawahara sites have been free from organized logging since around 1960.

Acknowledgements

We are grateful to staff at the Yakushima Nature Conservation Office, Yakushima Forest Environment Conservation Center, Kagoshima Prefecture, and Kami-Yaku town for granting permission to conduct our research activity.

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All listed documents are written in Japanese.

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Yaku-town Local History Editing Committee (2003) Local history of Yaku-town 3 – Rural community 3. Yaku-town Education Board. Yaku-town.

Details unknown (1882) Old map of Yakushima, owned by the Kagoshima prefecture library.

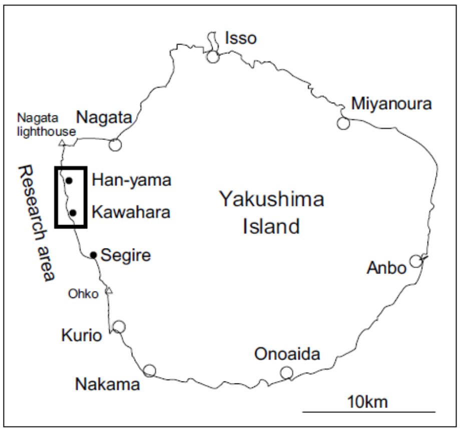

Fig. 1. Location of study site in the western lowland of Yakushima Island.
Black circle, abandoned villages; white circle, major towns; triangle, places related to text.

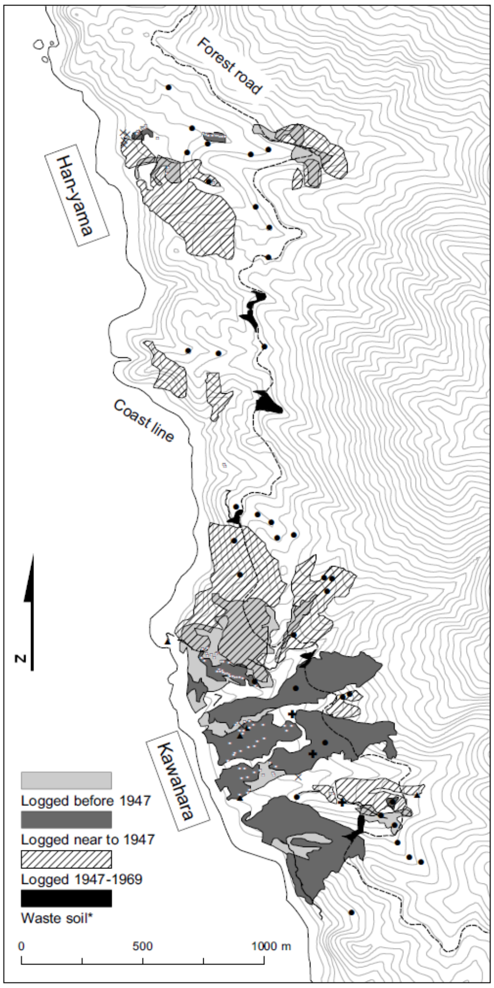

Fig. 2. Location map of abandoned artificial structures such as charcoal kilns, houses, farm fields, and trails with stone masonry. Numbers on some stone kilns indicate the year of abandonment, estimated by tree-ring analysis for *Melia azedarach* var. *subtripinnata* standing adjacent to a kiln.
* Camphor trees, *Cinnamomum camphora* trees extracted tree-ring cores (12 trees at 3 sites).
** Pine stumps, fallen trees and stumps with V-shaped scars to collect resin.
The forest road was constructed in 1967. Contour interval is 20 m.

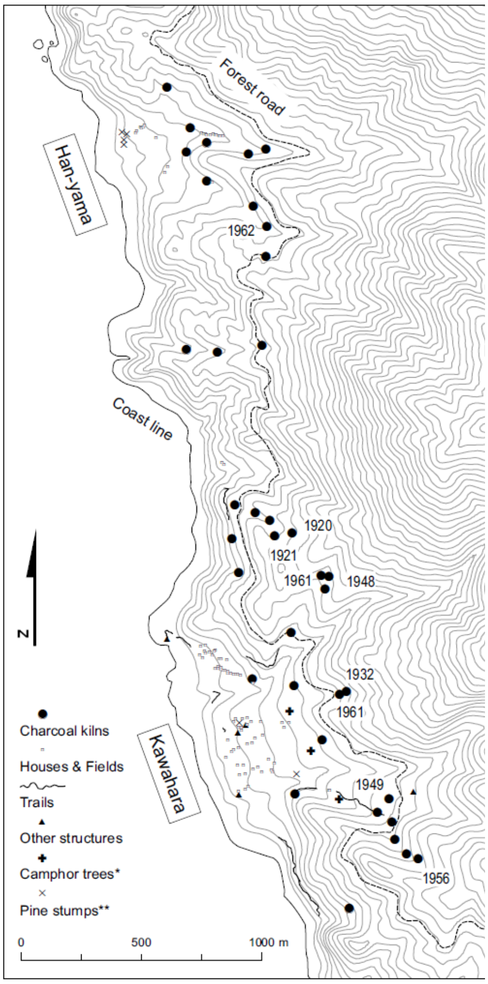

Fig. 3. Logged areas derived from aerial photos taken in 1947 and 1969.
Waste soil, bare ground due to waste soil associated with road construction in 1967.
See legends of Fig. 2 for the other symbols.

Historical GIS of Yakushima Island and the Extent of Human Subsistence Activities

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Introduction

Maps often provide important information about land use. Arranged in a time-series, maps can show land use change. However, cartographers have produced a wide variety of maps. For any particular study site, historical geographers need to examine available maps to determine what type of information can be obtained from the maps. For a research project applying a Geographic Information System (GIS), determining exactly how maps depict land use will point towards a strategy for data entry and analysis.

The most commonly used maps in Japan are the topographic maps produced by the Geographical Survey Institute (GSI) of the Ministry of Land, Infrastructure and Transport, and its predecessor institutions. These maps cover the entire land area of Japan. A historical geography project in Japan often starts by obtaining the map history for the topographic maps of a study site. While some parts of Japan may have been surveyed repeatedly by various Japanese government institutions, the earliest topographic map of the GSI will often be the first maps surveyed by modern methods, and the earliest extensive and complete record of land use, for many parts of Japan. A historical GIS project to study environmental changes in Japan must start first with an examination of the topographic maps to determine what they can tell researchers about land use changes on this island.

The objective of this project is to construct a historical GIS database for Yakushima Island in southern Japan. The first step of this project was to examine exactly how Yakushima is depicted in the topographic maps issued by the GSI, and, second, use the topographic maps to carry out time-series analysis to identify major patterns of land use change associated with the livelihoods of the inhabitants.

The goal of this analysis is to identify the spatial extent of the daily subsistence activities carried out by the inhabitants of Yakushima. Human activity has undoubtedly affected the vegetation and land cover of Yakushima. The island has been inhabited since the neolithic Jomon period. In early modern times, the people of Yakushima lived by a combination of farming, fishery, and forestry. However, Yakushima is a mountainous island and human habitation is largely restricted to the coastal plains. While this fact is obvious, the extent to which human subsistence activities extended up the mountain-side is a critical research issue. Research on land use history is linked to a judgment about whether human activity in modern times is expanding or shrinking. In the case of Yakushima, modern farms, especially orchards, have expanded uphill into forested mountains in the post-WWII period. Thus, historical geographical research is necessary to determine whether human activity is expanding into new, previously unused areas.

This study focused, in particular, on a type of land use depicted in topographic maps called “are-chi,” which can be translated as roughland or wasteland. In Japanese topographic maps, wasteland denotes unforested grasslands or bushland (Japan International Map Association, 1990). In a heavily forested landscape as in Yakushima, wasteland implies the presence of human activity that cleared forest. First, the

GIS analysis mapped the estimated extent of wasteland, as well as farmland, as indicators of human activity on Yakushima. Second, time-series analysis identified the location of new land uses in relation to older land uses to determine whether the new land uses were expanding into previously unused areas.

Methods

Yakushima is covered by four map sheets at 1/50,000 scale and seven map sheets at 1/25,000 scale. This project used maps from three time periods for GIS analysis, as folllows: (1) 1/50,000 scale maps issued in 1921 in the Japanese polyhedral projection, the oldest topographic maps of Yakushima, (2) 1/50,000 scale maps issued in 1972-73, the earliest in the universal transverse mercator (UTM) projection, based on 1/25,000 maps drawn from 1969 aerial photographs and 1970 ground survey, and (3) 1/25,000 scale maps in the UTM projection issued in 1992 based on 1990 aerial photographs and 1991 ground survey. The maps were georeferenced to the same UTM projection (Tokyo datum, Zone 52) using corner latitude-longitude coordinates printed on the maps, and joined together into single maps for each period.

Land uses demarcated by lines were entered into the GIS as polygons. Land uses marked by free labels were first entered as points from which the GIS generated Theissen polygons, followed by merging all adjacent polygons with the same land use.

The data on altitude was based on the 50 meter-interval topographic data issued by the GSI. The analysis was confined to the area from the coast line up to an altitude of 500 meters above sea level since this project focused on the rural landscape, and large-scale forestry in the higher altitude mountains is beyond the scope of this particular analysis.

Land use change was analyzed, first with a comparison of land uses among the maps of the three time periods, and, second, with an overlay analysis of the three maps at two intervals between maps 1 and 2, and maps 1 and 3.

Results

Mapping history

The mapping history of Yakushima island shows that the first topographic maps of Yakushima were surveyed in 1921 at 1/50,000 scale. The mapping history for one of the 1/50,000 maps is shown in Table 1. These maps were probably the very first time Yakushima was mapped completely by modern cartographic methods. Examination of the maps issued in 1946, 1954, and 1962 found that cartographers had made almost no changes whatsoever compared to the 1921 map. The first map series drawn in UTM in 1972-73 was the first to be completely redrawn, and the map from this year at 1/50,000 scale is used for the present analysis. Subsequently, the GSI updated the maps periodically at both 1/25,000 and 1/50,000 scales. The 1/25,000 map issued 1992 is used as the third map in the present analysis.

Table 1. Mapping history of one of the four 1/50,000 topographic maps of Yakushima titled Northeast Yakushima.

Map number	History			Issue date
153-6- 1	1921	Taisho 10	Surveyed	30 Aug 1921
153-6- 2	1921	Taisho 10	Surveyed	30 Nov 1946
153-6- 3		Missing		
153-6- 4	1953	Showa 28	Updated	30 Apr 1962
153-6- 5	1972	Showa 47	Edited	28 Dec 1973
153-6- 6	1953	Showa 28	Updated	30 Nov 1954
153-6- 7	1978	Showa 53	Modified	30 Nov 1978
153-6- 8	1989	Heisei 1	Additions	1 Sep 1990
153-6- 9AB	1993	Heisei 5	Modified	1 Jul 1994

Land use depicted on Japanese topographic maps

An important characteristic of the GSI topographic maps is that some land uses are demarcated with linear boundaries while others are free labels. The land uses with line boundaries in the maps of Yakushima are rice paddy, dry field, orchard, villages, and some urban areas. These land uses entered the GIS as polygons. The free labels depict broad leaf forest, coniferous forest, wasteland, and some free-standing buildings. These labels are scattered throughout the maps outside of the land uses depicted as polygons. The labels can be used in GIS analysis as points, or they can be used to generate polygons estimating the areas of the two forest types and wasteland. Polygon boundaries were generated from Thiessen polygons based on label points of forests and wasteland as described above. No free-standing buildings were depicted in the 1921 map, and the free-standing buildings in the later maps were ignored for this analysis. Since the labels for forests or wasteland were often clustered, the Thiessen-based polygons depict zones of forest or wasteland. The under-500 m area of Yakushima comprises 45% of the island. All rice paddies, fields, orchards and villages existed in the under-500 m area in all three maps. Figures 1 and 2 show land use within the under-500 m area as depicted in the three topographic maps. The 1921 map depicts the same villages that exist today, although the village settlements appear to be confined to smaller areas. Only a single road is drawn into the 1921 map linking the villages. The map shows large fields and rice paddies around some of the larger villages, and small fields scattered along the coast. Otherwise, the 1921 map is devoid of detail compared to later maps. Wasteland labels, however, are found in many parts of the under-500 m area of the island in the 1921 map. The polygons generated from the wasteland labels cover large areas. Orchards did not exist at all in 1921 map. In the maps of 1972-73 and 1992, orchards are a prominent land use. Many orchards are located along the foothills of the mountains (Figure 2). The highest orchard reach an altitude of about 285 m.

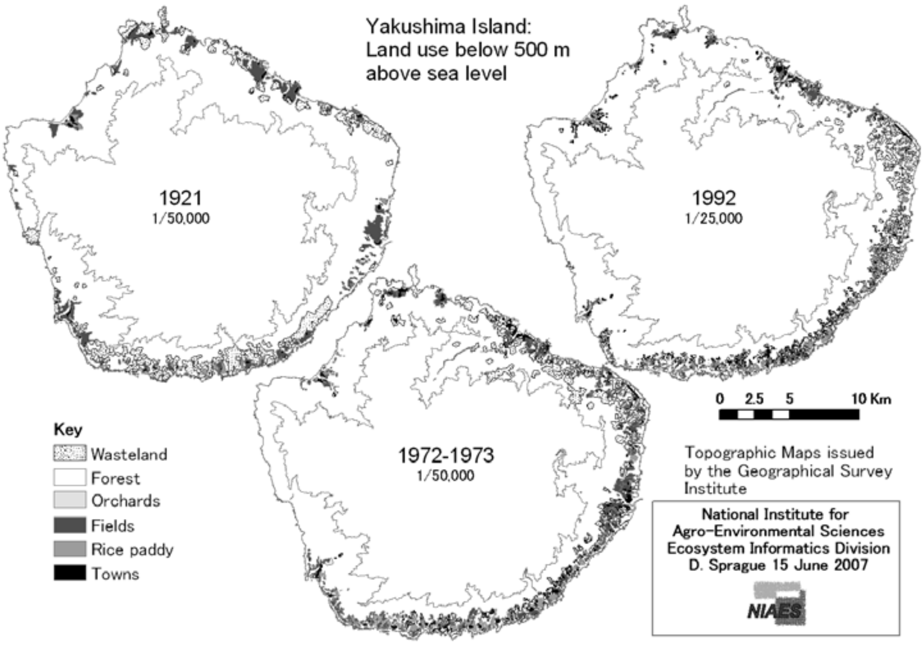

Figure 1. Land use below 500 m above sea level on Yakushima Island reconstructed from topographic maps of three periods.

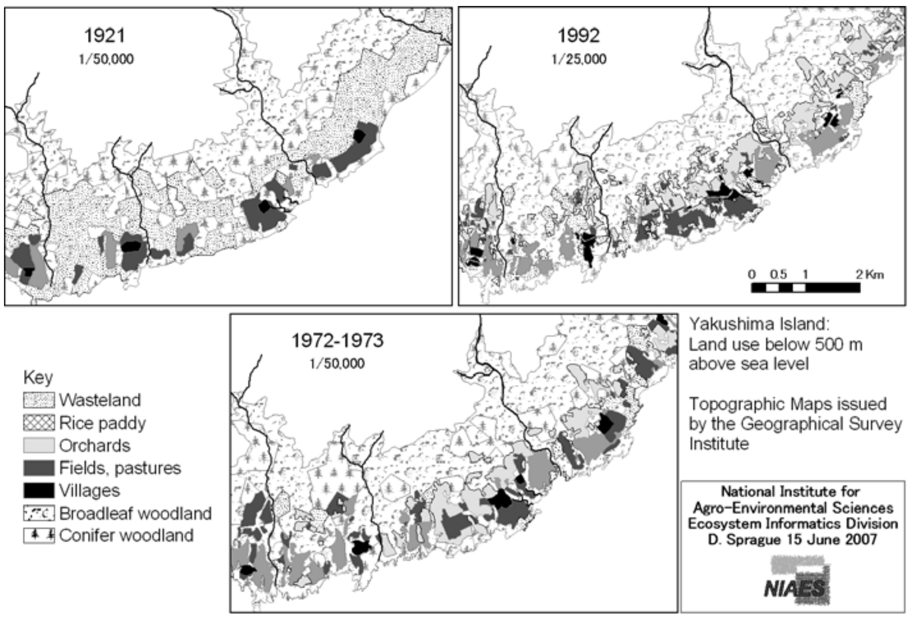

Figure 2. Detail of land use below 500 m above sea level on the southwest side of Yakushima Island reconstructed from topographic maps of three periods.

The proportions of land use depicted in the maps changed among the three periods (Figure 3). Wasteland area was highest in the 1921 map and subsequently declined. Nevertheless, wasteland continued to be the largest land use type, excluding forests, in the area under-500 m in all three periods. Rice paddy and field areas were highest in the 1972-73 map and declined in the 1992 map. Orchards, which did not exist in the 1921 map, appeared from the 1972-73 map, and increased in area in the 1992 map. Villages and urban areas increased steadily from the earliest to the latest map, although urban area is slightly underestimated in the later periods since the free-standing buildings are ignored in this analysis.

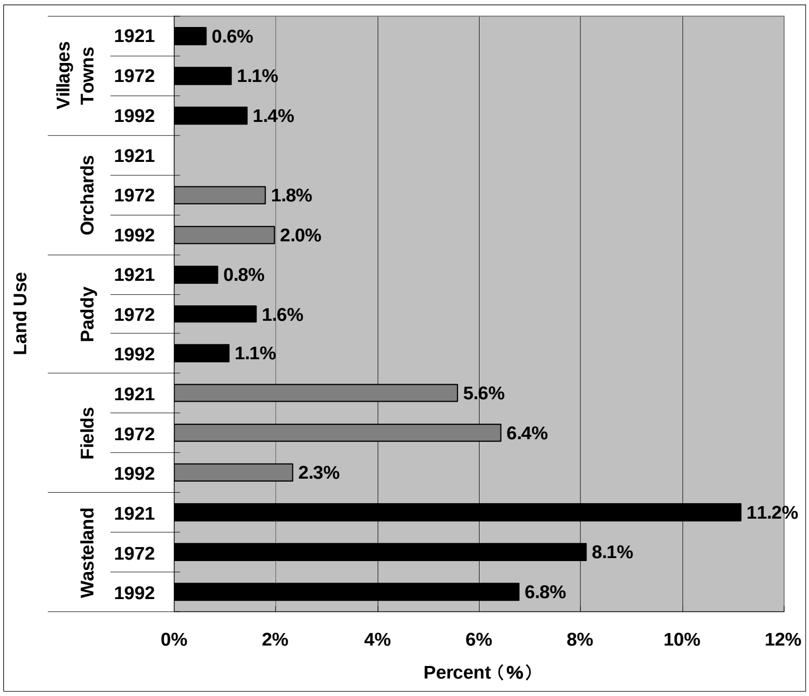

Figure 3. Land use change below 500 m above sea level in Yakushima Island as reconstructed from topographic maps of three periods

Altitude distribution of wasteland

The 1921 map contained 430 wasteland label points. The wasteland point farthest inland was located 2,015 m from the coast. The altitude distribution of the wasteland points showed that a large proportion were distributed at fairly low altitudes, with 90% located under about 200 m. However, the highest wasteland point was located at 459.6 m above sea level (Figure 4).

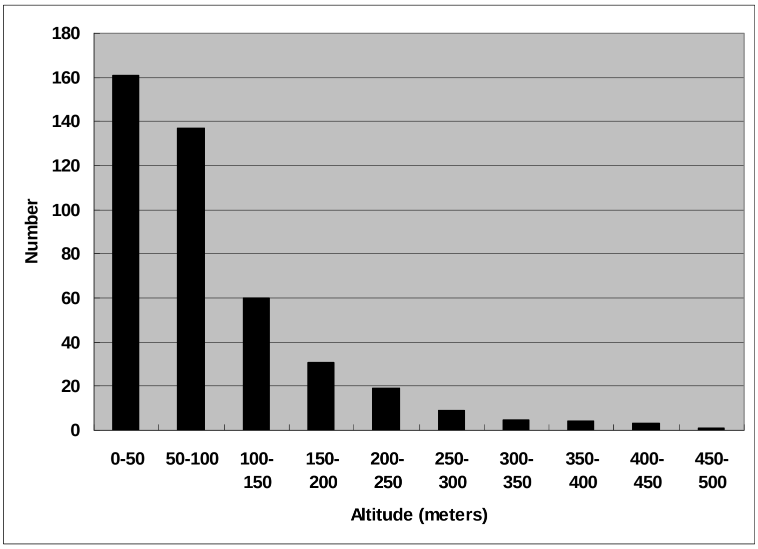

Figure 4. Altitudinal distribution of wasteland labels on 1921 topographic map of Yakushima Island.

Source land uses of orchards

The central research question of this project is whether modern land uses, especially orchards, can be considered an expansion of intensive human activity over a larger area compared to historical land uses. The expansion hypothesis would be supported if land uses in later maps tended to be located in what had been forests in earlier maps. A land use change hypothesis is supported if some type of land use besides forestry had been taking place in a particular location in both earlier and later maps.

The maps reveal that the orchards were cleared in the same area and altitude generally as wastelands (Figures 1 and 2). The overlay analysis provides a more precise, quantitative measure of the overlap between orchards and past wastelands (Table 2). Wasteland in the 1921 map was the source land use for 42% of orchards in the 1972-73 map, and 36.8% in the 1992 map. Other past land uses in 1921 made way for orchards in later periods. In the 1972-73 map, 6.8% of orchards existed in former fields or rice paddy, and in the 1992 map, 19.2% of the orchards existed in former fields or rice paddy. It is important to point out, however, that about 50% of orchards in 1972, and 43% of orchards in 1992, were located in areas depicted as some type of forest in 1921.

Table 2. Source land use in the 1921 topographic map of orchards in the maps of 1972-73 and 1992 after overlay analysis.

	Land use in:	
Source land use:	1972	1992
1921	Orchard	Orchard
1 Wasteland	42.8%	36.8%
2 Broadleaf	21.3%	14.4%
3 Conifer	29.1%	28.5%
4 Fields	6.1%	15.7%
5 Wet paddy	0.0%	0.0%
6 Dry paddy	0.7%	3.5%
7 Villages	0.0%	1.1%
Total	100.0%	100.0%

Discussion

No geographical study on Yakushima, or in any other part of Japan, would be complete without an examination of topographic maps, and they provide the initial data for further detailed research. Wasteland accounted for a large proportion of land in the under-500 m area of the island, implying that some sort of human activity had prevented these areas from succeeding naturally to forest. Although fields and rice paddies were confined to a smaller area in the 1921 map compared to later maps, the large wastelands suggest that human subsistence activity had extended more broadly throughout the lower altitude regions of Yakushima compared to the extent of permanent fields or villages. Wasteland could extend quite far uphill, up to nearly 500 m above sea level.

Wasteland depicted on topographic maps may have been produced by a variety of human activities. Wasteland may have been grasslands that farmers maintained by repeated cutting or firing. Under traditional Japanese agriculture, farmers obtained natural resources locally to support their livelihoods, such as green fertilizer, fodder, firewood, or charcoal. On Yakushima, the town histories refer to the practice of swidden agriculture around villages, the importance of charcoal production, and some pasturing of horses (Yaku Township, 1994).

Orchard expansion can give a present-day observer the impression that human activity in general had been expanding. Orchards are a modern form of agriculture. The first orange plants were introduced to the island in 1924 (Yaku Township, 1994). Orchards are absent from the 1921 map but appear from the 1972-73 map. Orchard area has expanded, and often expanded upwards to become the fields located at the highest altitudes among all forms of agriculture. Orchard expansion in some places was accompanied by the expansion of road networks uphill. Mature forests surround many orchards today (Sprague, 2007).

However, the GIS overlay analysis found that a large proportion of the orchards had been built in former wasteland or former fields. The 1921 topographic map shows large areas of wasteland. The altitudinal distribution of orchards generally matches that of wasteland. The highest orchards in the 1992 map reached 285 m. Although 90% of the wasteland labels were located less than 200 m, wasteland labels were located as high as 460 m above sea level. These data lend support to the hypothesis that the orchards were expanded into altitudes that had historically been under the influence of the subsistence activities of the residents of Yakushima.

Some orchards were built in areas that had been labeled as forest in the 1921 map. The topographic maps do not provide sufficient details about forests to judge whether these forests were primary or secondary forests. However, it is reasonable to assume that many of these forests were secondary forests or tree plantations. These forests were within the same altitudinal zone as orchards and wasteland, and the residents of Yakushima were known to have harvested forest resources, such as charcoal or firewood. In addition, natural conifer at low altitudes is unusual in Yakushima, although this island is famous for natural, old-growth cedar forests at higher altitudes (Miyawaki, 1986). The low altitude conifers may have been pines, which were very common in rural Japan under traditional agriculture. Thus, the orchard expansion in forest perhaps can be considered a type of land use change rather than the expansion of human influence into previously pristine natural environments.

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Changes in Human Benefits and Values from Forest Services in Yakushima Island

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Introduction

Since the pre-modern period, the forest area in Yakushima Island, Japan, has experienced extensive human influence. Some of this influence has led to crucial changes in the forest environment in this area, and some reflects conflicts among stakeholders of the forest. These impacts fundamentally emerged because the range of forest services offered various types of benefits and values to the people. This paper aims to analyze the details and composition of and the changes in human benefits and values from the forest services in Yakushima Island in order to clarify how the relationship between the people and the forest has changed from the seventeenth century.

Basic Framework: Forest Services, Benefits, and Values

Table 1 classifies and details the existing forest services, benefits, and values provided by the forest in Yakushima Island. According to the results of analyses in field studies and the field of forest science (Clawson 1975, Hageneder 2005), I assume four basic forest services available to humans: provision of space for alternative uses, provision of materials for products, protection of the natural environment, and favorable effects on people's spiritual aspects. Further, I assume nine specific services that can clearly shed light on the human conflicts pertaining to this forest. Then, I also assume specific human benefits, based on nine fundamental human values regarding nature classified by S. Kellert (Kellert 1996, 1997) and my own research experience in the field.

This classification of and relationship among the forest services and their human benefits and values form the basic framework of the analysis presented in this paper, using which it can be clarified how humans, based on the benefits and values, formed the social structure surrounding the forest in each period and how they worked on and changed the forest environment in the island.

Six figures (Figure1-6) seen in the next chapter actually show overall compositions of these human values and benefits from the forest services in specific periods from the seventeenth century. In these figures, identified recipients who have same combinations of the benefits are represented as ellipses. Colors of the ellipses show attributes of the recipients. Black means the recipients living in the outside of the island, gray includes both living in the inside and outside, and white means almost all of them are living in the island. The benefits from the forest services recognized and enjoyed by them are represented as rectangles. Colors of the rectangles correspond to the colors that identify the nine specific forest services in the Table1. For example, a dark red rectangle of "material wealth" corresponds to the "material wealth" benefits from the forest service of "provision of commercial products."

Historical Change in the Composition of Human Benefits and Values from Forests

The Pre-modern Period ***(Seventeenth to the Early Nineteenth Century)***

＜Figure 1＞

From the beginning of the Edo Period, the pre-modern period in Japan, feudal rulers such as Tokugawa Shogunate and the Satsuma Domain focused on the forest service of provision of materials for commercial products in the island. Based on the benefit of “material wealth,” they expected to obtain large-diameter timbers for large constructions from the dense forest in the island. Satsuma Domain also regarded the forest, especially the ancient cedar trees (*Cryptomeria japonica*) known as *yakusugi* and aged over 1,000 years old, as a means of strengthening their finances. As a feudal obligation, they decided to charge sliced *yakusugi* timber known as *hiragi* toward the villagers. *Hiragi* and other forest products from the island were mainly sold in the western parts of Japan by domain-designated merchants from Kagoshima (the capital of the Satsuma Domain and Kagoshima Prefecture today) or Osaka. It can be concluded that this period is characterized by the process in which feudal organizations gradually conferred utilitarian values to the forest in the island; these organizations shared the benefit of material wealth from the forest service of provision of commercial products.

On the other hand, these feudal rulers also partly implemented afforestation in order to keep away wind and sand in coastal areas. This implies that they attempted to secure the benefits of local villagers on the forest service of “protecting lands, water, and daily life” in this period. Moreover, the fact that they designated hunting areas for the loads of the domain in the forest shows that the rulers also recognized the benefit of “spiritual elevation” on the forest service of offering human recreation at that time.

The villagers in the island mainly enjoyed the benefits of the forest service whereby they were provided space for living and farming, and provided products for daily use by the forest. They also relied on and felt an affinity toward the dense forest and old trees covering the island. The spiritual benefits enjoyed by the villagers are confirmed by the fact that one of the public events involved visiting mountains to pay homage to the god and spirit residing in the forests and mountains. Of course, they simultaneously enjoyed the benefit of accumulating commercial goods and material wealth while they engaged in *hiragi* production and illegal timber trading.

In general, the recipients of the benefits and values were limited under the Shogunate system under which access to the outside world was restricted in this period. Therefore, the composition of the benefits and values from the forest services in Yakushima Island was relatively simple and did not reflect serious conflicts among the recipients, or drastic changes in the forest environment.

From the Meiji Restoration to the Administrative Lawsuit ***(1868–1920)***

＜Figure 2＞

In the Meiji period when Japan initiated industrialization and modern nation-state building, the composition of the benefits and values from the forest became increasingly complex.

Soon after the Meiji Restoration, the new administration decided to abolish class distinctions in the old regime, including the warrior class, and promote industrial development in order to increase state power.

Because of these policies, the former warrior class of the Satsuma Domain had to find a new means of earning a living, and the local government supported their immigration to Yakushima Island and allowed them to engage in forest production and exploitation in order to make them contribute to regional development. However, when both the number of immigrants and the amount of timber harvested by them increased in the island, the local villagers felt that the benefits they were receiving from forest services, such as obtaining products for daily use or accumulating commercial goods, were under threat. As a result, conflicts concerning forest usage occurred between the villagers and immigrants on the forest border.

The other factor that changed the composition of benefits and values in this period was the nationalization of the forest under the prevalence of the modern property rights system. After several investigations conducted in the late nineteenth century, more than 90% of the forest area in the island was designated as state owned. This nationalization reflected the commercial benefit of material wealth of the Meiji administration. The connection between the Ministry of Agricultural and Commercial Affairs and local forestry offices represented this stance, and the administration intended to exclusively maintain and produce high-quality timber in order to satisfy the demand for nation-state building.

Facing the tightening of bans and regulations in the nationalized forest area, the villagers again felt that their benefits and values were being restricted. They not only repeatedly sent petitions to the local government and forestry offices in order to regain their right to the forest surrounding their villages but also engaged in illegal lumbering to express passive resistance.

This latent conflict between the administration and villagers surfaced in the administrative lawsuit from 1904 to 1920 in which villagers claimed to regain the state-owned forest. However, during these 16 years of the trial, the claim of the complainant was not based on the benefits and values of the villagers alone. Large capitalist organizations, such as newly formed conglomerates producing timbers, actively supported villagers as a proxy for the plaintiff. In return for the support, the villagers signed a contract stating that if they won the lawsuit, these organizations could get more than around half of the commercial revenue from the disputed forest. It was clear that these external capitalist organizations wanted to enjoy the commercial benefit of material wealth from the forest in this island and therefore supported the villagers during the trial. At the last stage, different strategies toward the lawsuit and paybacks offered by multiple external organization led to internal rifts among the villagers.

This process shows that in the context of industrialization, the diffusion of modern market economy, and property rights, the recipients who focused on the benefits and values of the forest in Yakushima Island were divided. Based mainly on the commercial benefit of material wealth, the human relationship concerning the forest became more complex with many conflicts. On June 7, 1920, the administrative lawsuit concluded with the dismissal of the villagers' claim. This result legitimized continued forest management by the state for most of the forest area in the island from then on.

The Start of Full-scale Operation by State Entities during the War Period **（1921–1945）**

＜Figure 3＞

The harsh result of the lawsuit put the villagers in very difficult situation since they had been deprived of means by which to accumulate goods from the forest and had accumulated substantial debt during the 16 years of the lawsuit. In 1921, the local office of the national forestry administration, in response to this situation, decided to allocate 7,000 ha of the forest area in the coastal mountains as “commitment forest” (*itaku-lin*). In this zone, the villagers were allowed to purchase forest products for commercial trade and daily use. At the beginning of the war period in the 1930s, this commitment forest gradually became the area in which materials for military demands were produced, such as charcoal for fuel, camphor for gunpowder, and birdlime for medical products. Through the regional and local government and the national forestry administration, the central government mobilized the villagers to large-scale operation to produce these goods in this zone. In particular, the charcoal formed in dense broadleaf forests in this zone was highly valued in this period.

In the other forest areas of the island, full-scale operation conducted by the national forest administration started immediately after the lawsuit ended. This operation, based on purchasing the commercial products of the forest, involved the cutting and use of large-diameter timber, such as those from ancient cedars. The operation was partly restricted to the zone in which the administration had decided to preserve forest vegetation for water purification and land protection, which meant that at least the benefit from the forest service involving protection of the natural environment was publicly recognized.

Another restriction of the operation based on commercial benefits rose from the increase in the benefits characterized by the scientific and aesthetic values of the forest. In 1921, two areas comprising 4,413 ha of state-owned forests were designated as “forest preserved for scientific purposes” and were also designated as a national monument managed by the Ministry of Home Affairs. These designations reflected the growing calls for preservation from famous biologists, ecologists, and forest scientists who had visited the island forest for research. They insisted on the importance of the extremely beautiful physiognomy and biodiversity of the forest in terms of future development of sciences and human wisdom, and many government officials and foresters also supported this argument. Based on the framework of this paper, this claim can be regarded as a combination of the “knowledge expansion” benefit of the “preservation of biodiversity” forest service, and “spiritual elevation” benefit of the “beautiful and communal landscape” forest service, both of which are strongly characterized by scientific and aesthetic values. As a reflection of these benefits and values, the national forestry administration had to begin, at least to some extent, preserving a part of the forest in Yakushima Island around the same time as starting full-scale operation.

***The Period of Economic Growth after the War*（1946–1960s）**

＜Figure 4＞

For more than 20 years after the Second World War, Japan experienced postwar reconstruction and economic growth, and the commercial benefit of material wealth based on utilitarian value was still a core factor for the characterization of the composition of the benefits and values from the forest in the island. However, changes in the stakeholders and produced materials concerning this benefit distinguished the composition in this period from those in the previous periods.

The first phenomenon that was observed after the war was an increase in the number of immigrants to the island, including those who came back from the front and former colonies, and these immigrants exploited the forests around the coastal areas to earn a living. This implied that at the end of the war, the benefits from the forest service of provision of space for alternative uses were highlighted again. Due to this movement, the area covered by the state-owned forest decreased around 660 ha in this period (Local Offices of National Forestry Administration, 1951).

In this period, a second movement arose in the former commitment forest that was renamed "shared-use forest" (*kyoyo-lin*). As the war ended and an energy revolution from biomass fuels to gas and oil occurred in local societies in Japan, the benefits for the government and villagers who produced materials for commercial and daily use from the commitment forest in the previous periods were suddenly eliminated. From 1945 to the 1950s, cooperatives that comprised villagers and led the production in the commitment forest in the war period were dissolved. Therefore, the stakeholders, especially the villagers, were forced to find new ways to enjoy the benefits offered by the zoned forests near residential areas.

An increase in the demand for timber and pulp during the Korean War and economic reconstruction yielded a solution to this situation. In 1963, encouraged by the government of Kagoshima Prefecture, major paper enterprises and local timber and paper companies jointly established the Yakushima Forest Development Cooperation. This cooperation and the companies involved signed contracts with the national forestry administration, and they hired residents and undertook the task of cutting broadleaf forests in this zone and producing pulp. The Public Corporation for Forest Development handled regeneration and management of the cleared area; this other new entity was run by the prefecture government, the town councils (two former villages grew into two towns at the end of the 1950s), and local communities (natural villages) that formed the cooperatives for the shared-use forest.

Reflecting this increase in the demand for timber, logging in other state-owned forest areas also increased in this period. The local office of the national forestry administration allowed immigration of many workers specialized in logging. They lived in the dense forest in the center of the island and engaged in logging of large-diameter timbers. Further, from the 1960s, some people living in the capital of Kagoshima Prefecture started the business of processing ancient cedars from the island for crafting products. They were distributed the cedars for crafts by the local office and enjoyed commercial benefits such as material wealth, knowledge expansion, and worker identity.

Based on the above movements, this period can be characterized by the replacement of the old style of forest usage by the new stakeholders who also enjoyed the commercial benefits of the forest, and gave new valuations. Reflecting this replacement, the people and organizations associated with the forest clearly changed. However, the recipients of the benefits and values from outside the island, such as the governments and companies, remained the key players in the drastic changes in the forest environment.

In this period, one of the human actions in the forest that clearly deviated from the commercial benefits was observed, as well as the previous period, in the benefits and actions supported by the scientific and aesthetic values on the forest. As a reflection of the benefits they received, i.e., expanding scientific knowledge on biodiversity and the spiritual elevation afforded by the beautiful forest landscapes in the island, scientists and conservationists lobbied for the Ministry of the Health and Welfare of the central government to designate the core forest area in the island as a national park. In March 1964, some forests in the central part of the island were designated as conservation areas of a national park. This designation also enhanced the potential human benefits from the forest services in the island, whereby people could enjoy the beautiful forest landscape and recreation and receive healthcare. Many tourists and trekkers subsequently visited the island to enjoy these benefits.

Another action against the distribution of the commercial values of the forest was based on a sense of danger regarding the clearing of the forest for timber and pulp production. In the late stage of this period, this sense gradually transformed into a voice that demanded the cessation of reckless clearing. Besides the scientists and conservationists from outside the island, some of the local residents also played a major role in this movement, and this reflected their sentiments toward the ancient cedar trees or the local identity felt toward the communal forest. In the next period, these residents behaving as conservationists played the main roles in consecutive campaigns for protecting the forests against the national forestry administration and companies promoting the operation who desired commercial benefits. However, the benefits and values they received from the forest were related to their life on the island; therefore, latent hostility toward foreign entities such as tourists and environmentalists who actually supported the campaigns also gradually surfaced since the population and garbage in the forest increased because of the tourists in this period.

Increasing Conservation Campaigns and the Decline of Commercial Forestry （1972–1993）

＜Figure 5＞

In Yakushima Island, the period from the 1970s to the 1980s was characterized by two movements: forest conservation campaigns extending from the conservational action from the previous period and the downfall of commercial forestry in Japan due to a sharp increase in amount of timber imported under the global market economy.

In this period, people acting toward protecting the forest from clearing due to the associated commercial benefit had already formed one faction among the island residents. The leaders of this faction were “boomerang people” who had once lived and worked outside the island and then decided to return to their native villages. Their claim in the consecutive campaigns for forest conservation was based on the protection of three specific benefits from the forest: gaining security of life in the context of increasingly frequent landslides due to forest clearing, spiritual elevation, and shared awareness of the beautiful and communal forest landscape under the slogan of “protecting the beautiful forest in our home island.” The environment agency, biologists, ecologists, and environmental groups from outside the island, according to their own benefits and values, supported these campaigns. Their joint effort led to the designation of several protected forest areas, such as a Wilderness Area at Hanayama, and the expansion of special protection areas in the national park.

On the other side, the stakeholders of the forest interested in its commercial usage, such as the local office of the national forestry administration; timber and pulp companies; and residents engaged in forest production, including forestry workers and the managers of the processing business for crafting products, jointly tried to protect their commercial benefits from the forest in the beginning of the 1970s. At that time, the Kamiyaku and Yaku Town Councils became the battle stage for the two sides. However, global changes such as a decreasing demand for domestic wood production given the increase in the amount of timber imported and the switch-over in energy source and building materials from wood, and a worldwide increase in environmental awareness clearly supported the conservationists’ side. As a result, the councils authorized a series of resolutions that ordained a ban on cutting the ancient cedar trees or the forests in important areas, aiming to protect the land, precious species, and landscapes; this reflected the three main benefits from the forest that the resident conservationists regarded as local “common sense.” These resolutions contributed to spreading awareness of these benefits to all the residents.

In response to these campaigns and the decline in the commercial benefits from timber and pulp production, the national forestry administration gradually shifted their main purpose of forest management from materials production to land protection. Through this process, the focus of the conflict related to the commercial benefits of the forest changed from forest clearing to the production of old stumps of the ancient cedar trees for craft production. In this period, many people living outside the island operated the craft industry involving wood from the ancient cedars. From the 1980s onward, they continued to negotiate with the local office of the national forestry administration, conservationists, and craft industries within the island over the amount of old stumps available to them.

Overall, due to previous human actions on the forest and the global changes, a new type of human conflict concerning the forest surfaced for the first time on Yakushima Island. Both sides of the stakeholders concerning clearing the forest held clearly different benefits from the different categories of the forest services. This was not as previous conflicts only over the commercial benefits and services.

After the Designation of a World Natural Heritage （from 1993）

＜Figure 6＞

In the 1990s, the change in the benefits and values accelerated from that in the previous period. Forest operations based on commercial benefits were no longer sustainable. The benefits and values received by the villagers realigned according to this change. They seemed to internalize the benefits from the forest that the resident conservationists held in the past. Therefore, prominent conflicts that divided the residents cannot be identified in this period.

In December 1993, 10,263 ha of the forest area in Yakushima Island was designated as a World Natural Heritage based on a request by the Ministry of Environment and scientists who enjoyed the benefits and values regarding scientifically or ecologically precious biodiversity from the forest, and the tourism industry that expected to receive the benefit of material wealth through the development of ecotourism on the island. Due to this designation, Yakushima Island attracted worldwide attention, and the number of tourists increased dramatically. This led to the development of the tourism industry, which included not only large tourism enterprises from outside the island but also island residents who managed guesthouses, produced handicrafts as souvenirs, or worked as forest guides. Further, the number of people referred to as “new immigrants” also increased; these people came from outside the island and wished to live in the rich forest environment. Today, they account for around 10 percent of the population.

However, these people’s attention and social changes in the island due to the designation gradually highlighted a potential conflict between the foreigners and island residents with regard to differences in the benefits and values received. The new beneficiaries of the development of tourism in the 1990s, such as the tourism enterprises or the forest guides of the new immigrants, enjoyed the benefit of “material wealth” from the forest services of provision of “beautiful landscape” or “healthcare and recreation.” Further, the tourists and new immigrants enjoyed the benefits of “spiritual elevation” and “peace of mind” by visiting and living in the forest, sightseeing, or participating in recreational programs. However, the benefits and values enjoyed and internalized by the island residents in the previous periods differed from those of the tourists and new immigrants. Those residents’ benefits are, even equally from the forest service of giving favorable effects on human spirit, including the benefit of “shared awareness” of the communal forest landscape, “reliance” or “affinity” toward the forest and trees, “security of life” by protecting the forest, or accumulating knowledge and culture through contact with the diverse species in the forest, and all of these developed because they had lived for a long time in the villages on the island.

The abovementioned difference in the benefits and values from the forest led the island residents to feel that their benefits were ignored and interfered since the designation of a World Natural Heritage. Except for some recipients of the “new” benefits, several villagers were frustrated because in some cases, the recreational benefits were enjoyed entirely by the tourists or tourism enterprises and because the increased population hampered their original benefits due to changes in the shared forest because of an increase in the amount of garbage, deterioration around forest trails, and expansion of resort buildings.

The environmental administration, environmental groups, and scientists who had their own combinations of the benefits and values and supported the increase in the benefits for the residents with regard to forest protection in the previous period now appeared to be in a difficult position between the new recipients and residents.

Concluding Remarks

Based on the historical changes in the composition of the benefits and values from the forest services, the following concluding remarks can be derived.

First, it is concluded that the relationship between the people and the forest in Yakushima Island from the pre-modern period to recent times is very special in that almost all types of forest services, benefits, and values were recognized by various people and organizations. In this regard, the human conflicts and relationships concerning the forest created many variations within each period. The type of conflicts mainly over the commercial benefits in the pre-modern to war periods no longer existed in the 1970s when the conservationist side expressed its desire to protect the forest with their benefits and values. Further, this side was also divided, especially since the forest was designated a World Natural Heritage in 1993, and thus, it enjoyed the different benefits and values from the forest services.

Second, it can be confirmed that during the change in the relationship, the benefits and values received by the entities from outside the island, such as the modern state administration, large capitalist firms and companies from the Meiji period to the 1970s, scientists, and tourists, had strong impacts on the relationship while reflecting the global changes in each period, and these entities actually spearheaded the actual changes in the forest environment. The considerable attention and impact of these foreigners often created situations in which the residents of the island felt that their benefits and values from the forest were under threat.

However, the third conclusion is that these island born residents who accepted external impacts were not stable stakeholders who received only one combination of benefits and values. Besides the members changing over time because of the various types of immigrants, they also changed their standpoints and internal structure, while they accepted the impacts and revised the combinations of benefits and values from the forest. The shift to commercial benefits from the Meiji period and the internalization of the benefits for forest protection through the conservation campaigns in the 1970s are good examples of this.

An understanding of this complex and dynamic change in the composition of human benefits and values from forest services can clarify the human relationships and actions surrounding the forest in Yakushima Island and will offer good examples and implications in an effort to consider a sustainable relationship between the people and forests worldwide.

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Table1: Forest Services and Human Benefits and Values

Forest Services, Benefits, and Values			
Forest Services		Human Benefits	
Basic Services	Specific Services	Benefits	Merits of Benefits
Provision of Space for Alternative Uses	Provision of Space for Alternative Uses	Having Spaces for Life	People can exploit and divert forests in order to have spaces for building houses, clearing farmlands, or constructing factories.
		Having Material Wealth	From the diversions, people become able to accumulate goods through having products and selling it in the market. This is a typical way for people to accumulate goods and have material wealth in the modern world.
		Having Feeling of Accomplishment	Through the diversions of forests, people can have feeling of accomplishment and satisfaction, since they could change natural environment as they liked.
Provision of Materials for Products	Provision of Commercial Products	Having Material Wealth	Through the production and market trade of forest products, people can accumulate goods evaluated by the market.
		Expanding Knowledge	Through the commercial production, people can develop their knowledge about economic efficiency of using forest materials and species. This expantion of knowledge will not only help accumulating goods, but also bring intellectual satisfaction of some people.
		Having Worker Identity through Productions	Through the production and process of specific forest products, people can form identity as the workers and proud themselves on it. This feeling tends to be synonymous with their meaning of life.
	Provision of Products for Daily Use	Having Products for Daily Use	Through the securement of fuel, lumber, or food by hunting-gathering in forest, people can maintain and enjoy their affluent daily life.
		Expanding Knowledge	Through the process of the production, people can develop their knowledge about the reasonability of using forest materials and species. This expantion of knowledge will not only help having products, but also bring intellectual satisfaction of the people.
Protection of the Natural Environment	Preservation of Bio-Diversity	Having Material Wealth	In addition to "material wealth" in the other categories, this forest service can facilitate the enjoyment of this benefit in its own way. The best example of this is to increase agricultural or forest production by regulating ecosystem process in forest.
		Expanding Cultural Knowledge	Through the relationship with diverse species and ecosystems in forest, people can get local knowledge about their use, develop communication capability by featuring them, and increase ability for self-protection.
		Expanding Scientific Knowledge	To understand the mechanism, functions, or characteristics of diverse forest species and ecosystems, correlated with the whole mechanism of the earth and life, satisfies people's intellectual curiosity, and develops people's rational, scientific way of thinking.
	Protection of Lands, Water, and Daily Life	Gaining Security of Life	The functions of forest, such as water purification, protection of soil runoff and disruption, air purification, protection of wind, sand or tide, and mitigation of local crimate change prevent natural disasters. And people can reduce threats to their life.
		Indirectly Having Material Wealth	Through preserving and securing water, and protecting lands and soils, this forest service can support various types of human productive activities in which people purchase goods accumulation.
		Expanding Knowledge	To understand those functions can develop people's knowledge about the importance of forest on the secrity of their life or goods accumulation. This expantion of knowledge will help enjoying those benefits, and bring intellectual satisfaction of the people.
	Absorbance of Carbon Dioxide	Gaining Security of Life	Through prevention of the global warming, people can reduce potential risks from it, and gain the security of their life.
		Expanding Scientific Knowledge	According to the development of scientific knowledge about the mechanism and effects of forest as a carbon sink, people can get intellectual satisfaction.
Giving Favorable Effects on Human Spirit	Provision of Beautiful or Communal Landscape	Having Spiritual Elevation	Beautiful forest landscapes stimulate and satisfy human aesthetic sense, creative ability, or the spirit of self-sufficiency.
		Having Material Wealth	People can accumulate goods evaluated by the market through engaging in service-sector jobs based on beautiful, communal forest landscapes, such as tourist business, or fine arts dealers.
		Having Shared Awareness from Communal Landscape	To share communal forest landscape, people can form some sort of local identity or sense of unity. This supports to keep up someone's mental stability.
	Provision of Human Health Care and Recreation	Having Peace of Mind	Forest can creat the space and mood that reduce people's stress, depressive feeling, or tiredness, and make them relaxed.
		Having Spiritual Elevation	Mountain climbing, fishing, hunting, hiking in forest environment can stimulate and satisfy people's spirit of inquiry, adventure, and curiosity.
		Having Material Wealth	People can accumulate goods evaluated by the market through engaging in service-sector jobs on the recreations in forest, such as tourist business, forest guides, and instructors.
	Cultivation of Human Spiritual Cultures	Having Feelings of Reliance	People living in forests usually respect and have faith in dense forests or large, ancient trees surrounding them. This feeling becomes their cultural backborn, and increase their comfort in daily life.
		Having Feelings of Affinity	Wildlife, including forest species, can give people an avenue for developing the emotional capacities for attachment, bonding, intimacy, and companionship. This sense of affiliation reduces isolation or loneliness of them.

		Human Actions on Forest				Valuations
Human Values	Recipients	Human Actions on Forest		Characteristics of Human Actions on Forest		Economic Valuation
Values on Nature	Main Recipients of Benefits and Values	Human Actions on Forest	Objects of Human Actions in Forest	Imagined Term of Enjoyment of Benefits	Main Impacts on Forest Environment	
(S. Kellert)						
Utilitarian, Dominionistic, Negativistic	Residents, Farmers, Industrial Enterprises, Governments	Clearing, Diversion	Zone, Whole Area	Short Term	Decrease	Probable
Utilitarian	Farmers, Industrial Enterprises, Governments	Clearing, Diversion	Zone	Short Term	Decrease	Done
Dominionistic, Negativistic, Aesthetic	Settlers, Farmers, Scientists, Industrial Enterprises, Governments	Clearing, Diversion	Zone	Short or Middle Term	Decrease	Questionable
Utilitarian	Forest Farmers, Enterprises and Workers, Intermediate Agents, Consumers	Cutting, Regeneration, Plantation	Species, Zone	Short or Middle Term	Decrease, Constancy, Simplification	Done
Scientific, Utilitarian, Dominionistic, Aesthetic	Forest Scientists, Forestry Engineers, Forest Farmers, Enterprises and Workers	Cutting, Regeneration, Plantation	Species, Zone	Short or Middle Term	Decrease, Constancy, Simplification	Questionable
Utilitarian, Moralistic, Aesthetic, Dominionistic	Forestry Engineers, Forestry Enterprises and Workers, Processors	Cutting, Regeneration, Plantation	Species, Zone	Short or Middle Term	Decrease, Constancy, Simplification	Questionable
Utilitarian	Gatherers, Consumers	Cutting, Gathering, Regeneration	Species, Zone	Middle or Long Term	Constancy, Decrease, Second-Growth Forest	Probable
Scientific, Moralistic, Naturalistic, Utilitarian, Dominionistic, Aesthetic	Gatherers, Forest Scientists, Sociologists, Anthropologists	Cutting, Gathering, Regeneration	Species, Zone	Middle or Long Term	Constancy, Decrease, Second-Growth Forest	Questionable
Utilitarian, Moralistic(?)	Producers, Consumers, Engineers, Governments	Preservation, Afforestation, Gathering	Species, Zone	Long Term	Constancy, Increase, Diversification	Probable
Symbolic, Scientific, Naturalistic, Negativistic, Utilitarian	People in Local Societies, Producers, Engineers, Forklorists, Anthropologists	Preservation, Afforestation, Gathering	Species, Zone, Whole Area	Long Term	Constancy, Increase, Diversification	Questionable
Scientific, Aesthetic, Naturalistic, Dominionistic, Moralistic	Biologists, Ecologists, Earth Scientists	Preservation, Afforestation, Gathering	Genes, Species, Zone, Whole Area, Global Environment	Long Term	Constancy, Increase, Diversification	Questionable
Negativistic, Dominionistic, Moralistic, Utilitarian, Aesthetic	Residents, Governments	Preservation, Afforestation	Zone	Long Term	Constancy, Increase	Probable
Utilitarian	Farmers, Enterprises	Preservation, Afforestation	Zone	Long Term	Constancy, Increase	Probable
Scientific, Naturalistic, Moralistic, Utilitarian	Forest Scientists, Agriculturalists, Engineers, Farmers	Preservation, Afforestation	Zone	Long Term	Constancy, Increase	Questionable
Utilitarian, Moralistic	Everyone, Residents on Coast Areas, Governments, Environmental NGOs	Afforestation, Preservation	Whole Area, Global Environment	Long Term	Increase, Constancy	Questionable
Scientific, Naturalistic, Moralistic, Utilitarian, Negativistic	Scientists	Afforestation, Preservation	Whole Area, Global Environment	Long Term	Increase, Constancy	Questionable
Aesthetic, Naturalistic, Dominionistic	Everyone, Tourists, People in Local Societies	Preservation, Visting, Afforestation	Zone, Whole Area	Short, Middle, or Long Term	Constancy, Increase	Questionable
Utilitarian	Tourist Enterprises, Governments	Preservation, Visiting, Afforestation	Zone, Whole Area	Short, Middle, or Long Term	Constancy, Increase	Done
Moralistic, Aesthetic, Utilitarian	People in Local Societies, Governments	Preservation, Afforestation	Zone, Whole Area	Middle or Long Term	Constancy, Increase	Questionable
Naturalistic, Symbolic	Everyone, Tourists	Visiting, Preservation, Afforestation	Zone	Short, Middle, or Long Term	Constancy, Increase, Degradation	Questionable
Dominionistic, Naturalistic, Aesthetic, Negativistic	Nature Lovers, Outdoorsmen, Tourists	Visiting, Preservation, Afforestation	Zone	Short, Middle, or Long Term	Constancy, Increase, Degradation	Questionable
Utilitarian	Tourist Enterprises, Nature Guides, Instructors of Forest Recreations	Visiting, Preservation, Afforestation	Zone	Short, Middle, or Long Term	Constancy, Increase, Degradation	Done
Moralistic, Negativistic, Aesthetic, Naturalistic, Scientific, Utilitarian	Believers in Animism or Buddism···, Religious Leaders, Governments	Preservation	Species, Zone, Whole Area	Long Term	Constancy	Questionable
Humanistic, Aesthetic, Dominionistic, Naturalistic	People in Local Societies, Benefactors of Forestry, Nature Lovers	Preservation	Species, Zone, Whole Area	Long Term	Constancy	Questionable

Figure 1: The Pre-modern Period (17th to the early 19th Century)

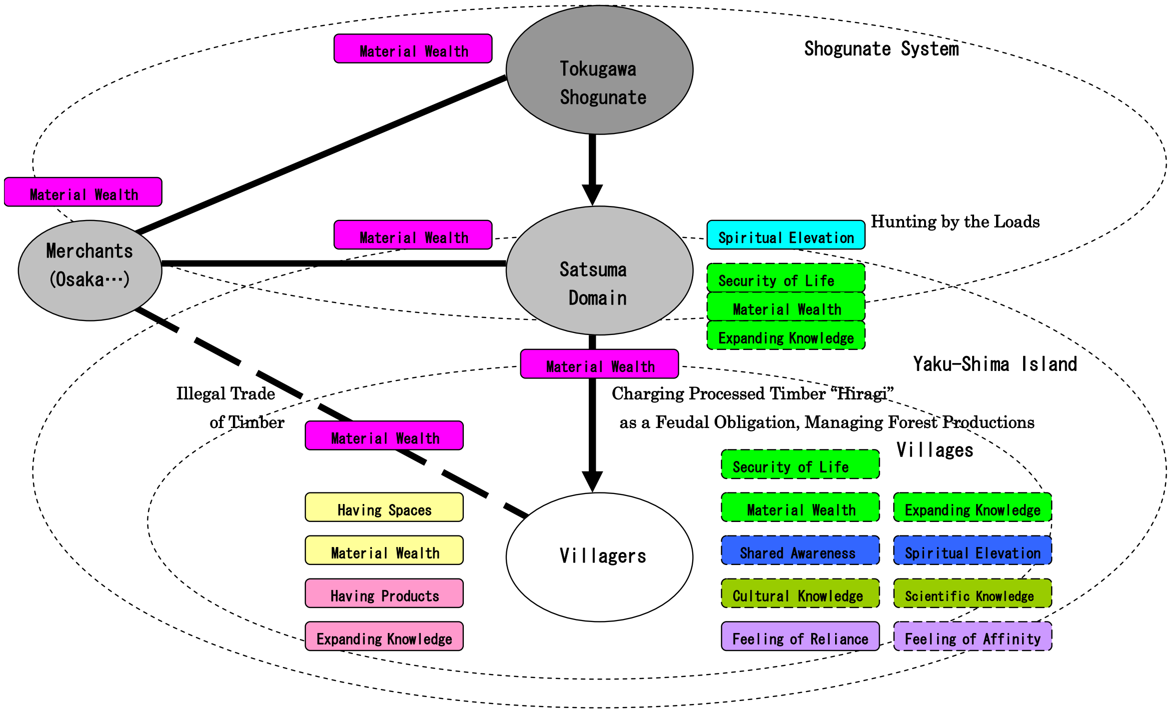


Figure 2: From the Meiji Restoration to the Administrative Lawsuit (1868 to 1920)

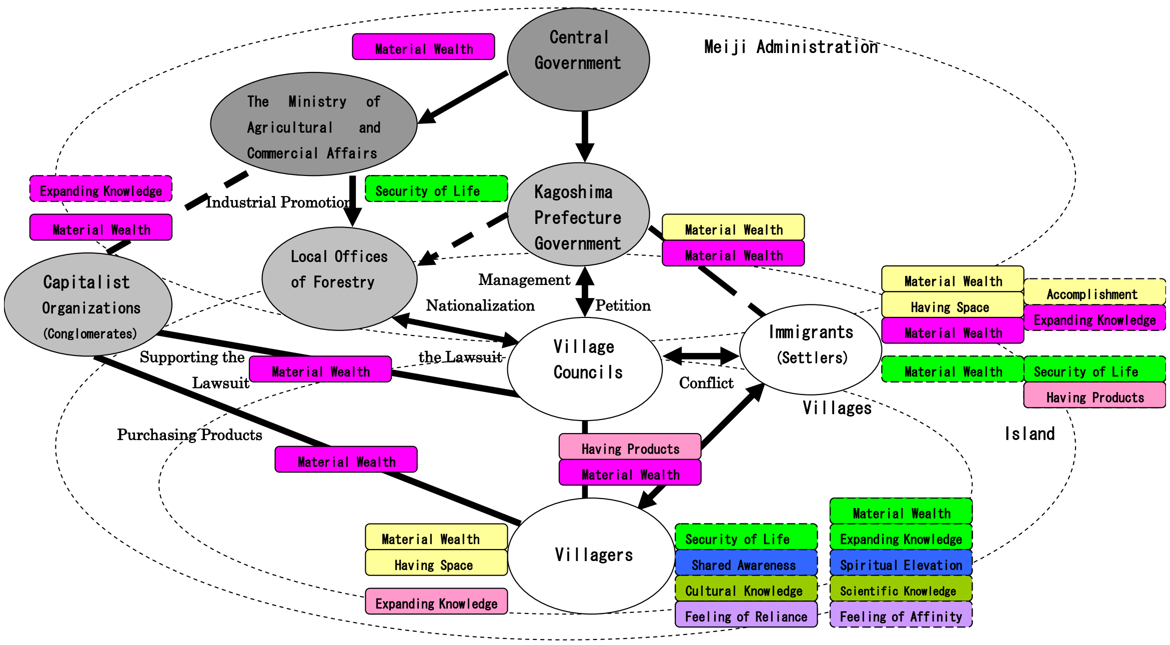


Figure 3: Under Full-Scale Operation during the War Period (1921 to 1945)

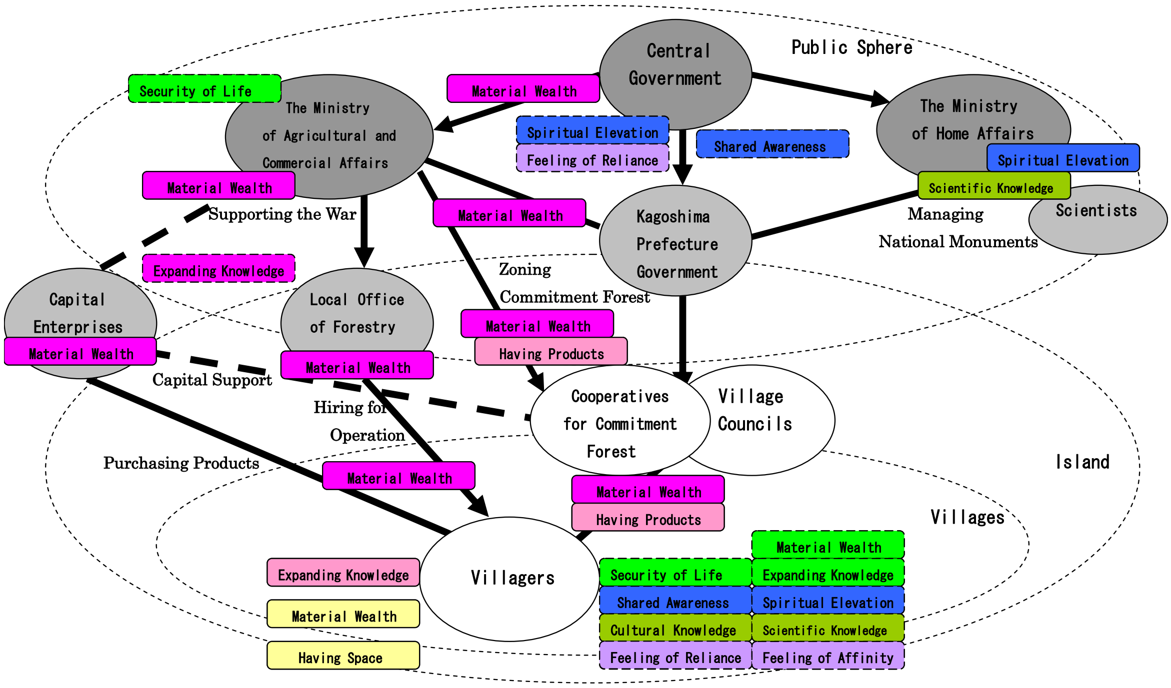


Figure 4: The Period of the Economic Growth after the War (1946 to 1960s)

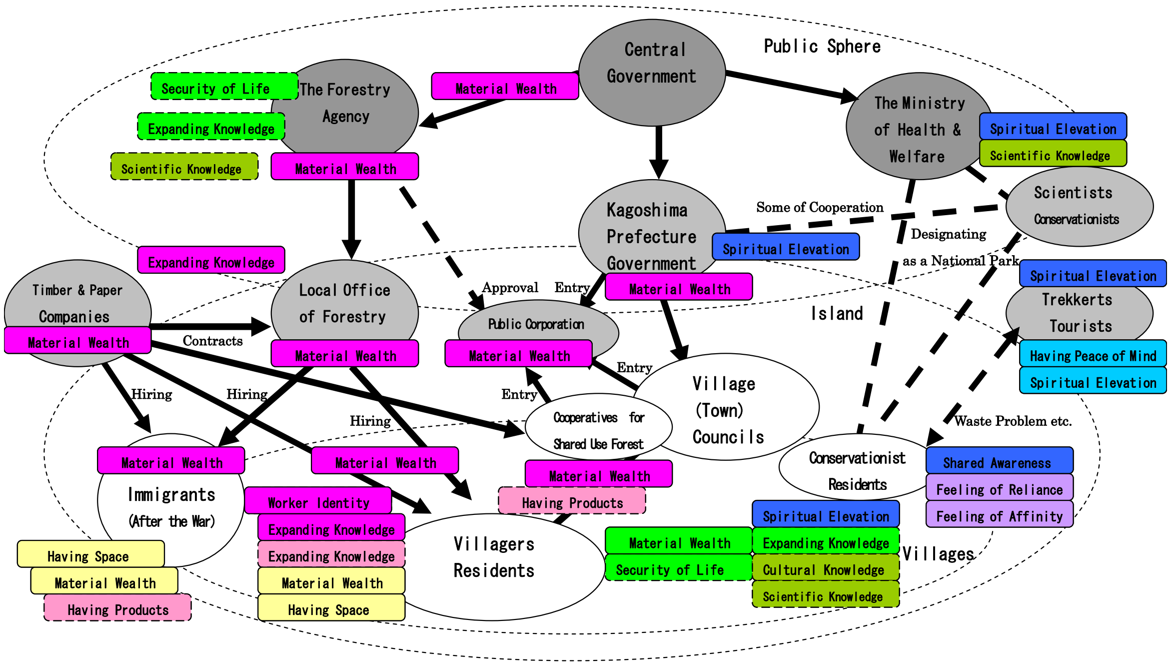


Figure 5: Conservation Campaigns and the Decline of Commercial Forestry (1972 to 1993)

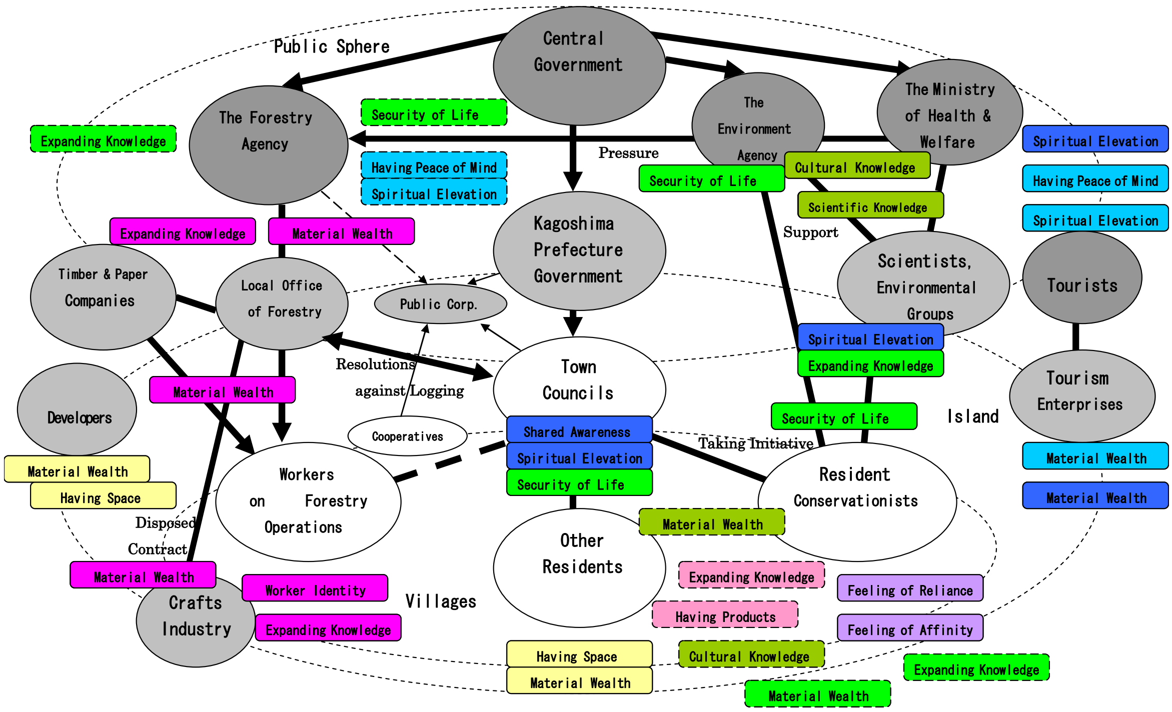
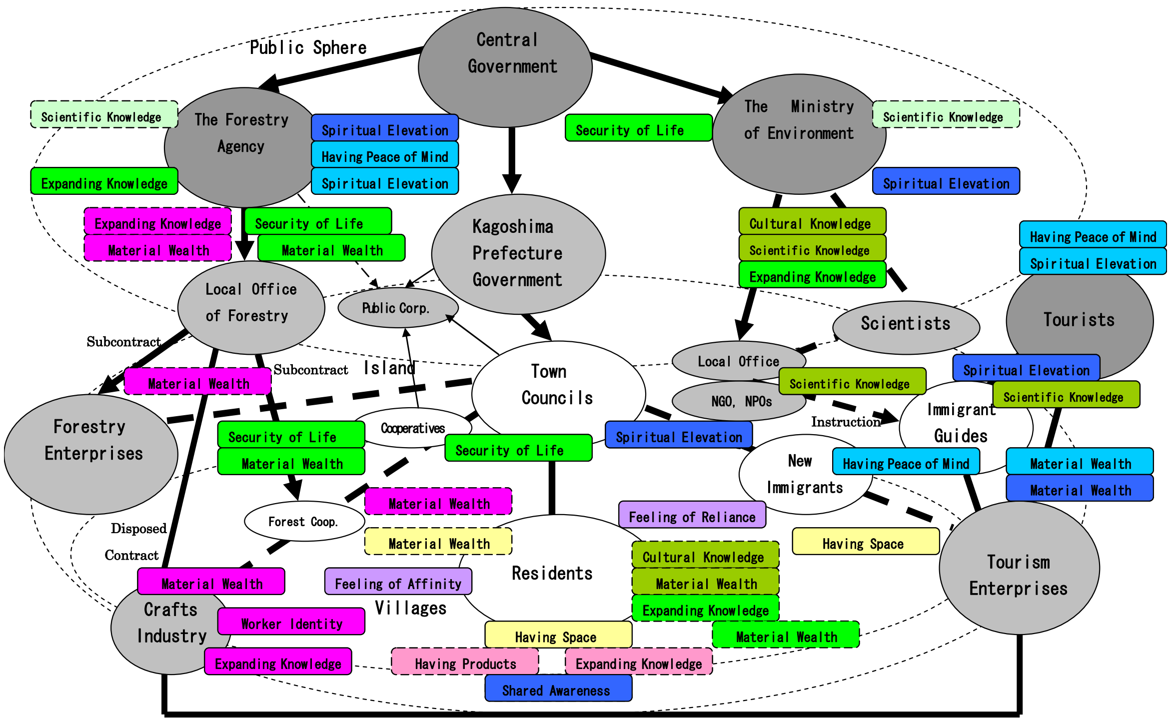


Figure 6: After the Designation of a World Natural Heritage (From 1993)



The Influence of Forest Resource Use on Forest Landscapes in the Abukuma Mountainous Area in the Past 90 Years

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Introduction

Understanding historical backgrounds can provide valuable insight into current ecosystems and biodiversity (Foster1992). Recent studies have further demonstrated that past land use and landscape changes significantly affect biodiversity (Courins and Eriksson 2002; Gachet et al. 2007).

Many studies have been conducted in Ogawa Forest Reserve, a remnant old-growth Fagus crenata forest in the southern part of the Abukuma mountains in Japan (Nakashizuka and Matsumoto 2002). It has been reported that the forest has been much affected by large-scale disturbances due to past land use (Suzuki 2002), but there is still a lack of detailed information concerning land use and landscape history in this region. Integration of comprehensive information on land use with the landscape history of the area surrounding the remnant old-growth forest could provide practical and useful information for planning the optimum conservation and management of this forested area as well as provide deep insights into the current biodiversity there.

The purposes of this study are 1) to clarify the socioeconomic forces which brought about changes in forest landscape around Ogawa Forest Reserve in the southern Abukuma mountains, utilizing literature surveys and interviews with local residents, and 2) to reconstruct past forest landscapes and quantify the landscape changes that have occurred from the beginning of the 20th century to the present, using old topographic maps and aerial photographs.

Methods

Study site

The study area covers about 10,000 ha of the Abukuma mountainous area in the Ibaraki and Fukushima prefectures of central Japan (Fig.1). The mean annual temperature is approximately 10.7°C and the mean annual precipitation is 1,910 mm (Mizoguchi et al., 2002). Hilly areas ranging from 600–700 m a. s. l. dominate a large part of the study area, and these have allowed horse production to prosper in the past. The forests have been subjected to substantial influence from human activity such as horse grazing, clearcutting for charcoal and fuelwood, and burning to maintain grasslands (Suzuki 2002). Most of the forest is now secondary forest or coniferous plantations, and only a few areas of old-growth forest remain. Ogawa Forest Reserve (OFR) was established in the national forest area in 1969 to preserve one of such rare old-growth, temperate, deciduous forests composed of *Fagus crenata*, *F. japonica Quercus mongolica* var. *crispula* and *Carpinus spp*. Forest covered approximately 8,800ha of the study area, and 77% of that is national forest. The area of private forest is minor, and most of the lands owned by private landowners are small in size.

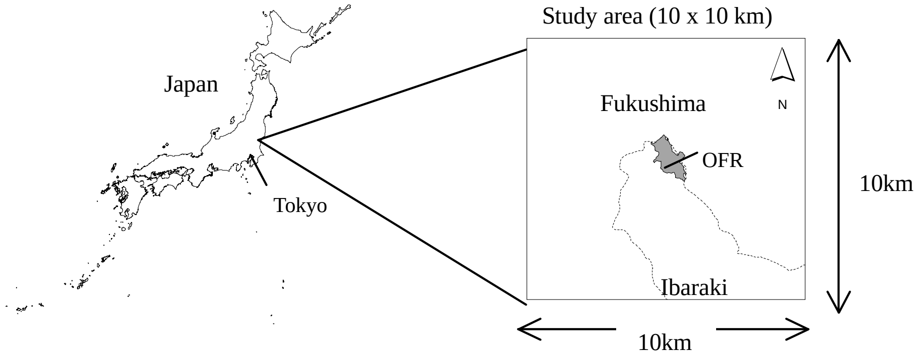

Fig.1 Location of study area. The study area covers about 10,000ha of the southern Abukuma mountainous area. It incorporates the 100 ha Ogawa Forest Reserve(OFR).

Interview and literature survey about forest resource use

We conducted interviews with local residents to clarify the socioeconomic forces which caused changes in land use. In the interviews, we inquired about the changes in forest types and forest resource uses, and also about their causes. Since we focused particularly on the changes around OFR, we conducted interviews with local residents of the Sadanami and Ogawa areas of Kitaibaraki city, Ibaraki prefecture where OFR is located. Interviews were conducted with elderly people in the village, such as the village headman, people who had worked at the local forestry office, and people who knew the history of village well. Since it was difficult to interview a large number of people and to obtain precise information on detailed conditions dating as far back as 90 years ago from interviews alone, we also referenced literature about local history and national forest management plans.

Reconstruction of past land uses

We identified the major turning points of the forest resource use from the interviews, and prepared multiple land use maps corresponding to them to understand landscape transitions. Data on past forest landscapes was obtained from old topographic maps at a scale of 1:50,000 published by the Geographical Survey Institute in 1908. In addition, we used aerial photographs at four time points: (1) the earliest available black and white aerial photographs, at a scale of 1:40,000, taken by the U.S. military in 1947; (2) black and white aerial photographs at a scale of 1:16,000 taken by Japan's Forest Agency in 1962; (3) color aerial photographs at scale of 1:10,000 taken by Japan's Geographical Survey Institute in 1975; and (4) the most recent black and white aerial photographs, available at scale of 1:16,000, taken by Japan's Forest Agency in 1997. The land use patterns were classified into four categories: grasslands, deciduous broad-leaved forests (deciduous forests), coniferous plantations, and other land uses. Grasslands include pastures, meadows, and cutover lands. Deciduous forests are dominated by Quercus serrata, Q. crispula, Castanea crenata, Carpinus laxiflora, and Carpinus tschonoskii. Coniferous plantations include Cryptomeria japonica and Chamaecyparis obtusa. Other land uses include agricultural fields, villages, and public facilities. All land use maps were prepared as vector maps using GIS software TNTmips Ver. 6.8 (MicroImages Inc.). The areas of each land use were calculated to determine the quantitative changes of the land use.

Results

Changes in forest resource uses

Based on the literature survey and the interviews, the pattern of forest resource uses was divided into three periods: (1) the period from pre-war to the post-war reconstruction period, characterized by multi-use of timber and non-timber forest products such as producing fuelwood and charcoal, pasturing and mowing, and collecting fertilizer for agricultural fields, (2) the economic growth period, characterized by the start of a decrease in most uses of forest resources and by the promotion of conifer planting, and (3) the stable growth period, characterized by the decline of forest resource use (Fig.2).

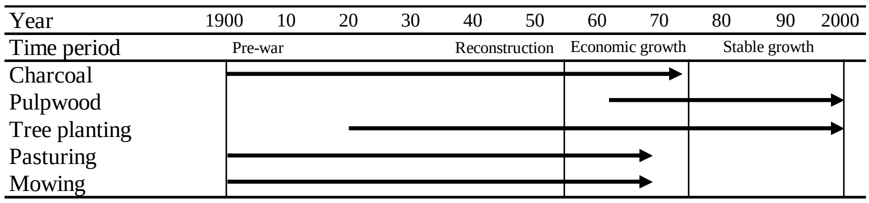

Fig.2 Changes in forest resource uses

Pre-war to reconstruction period (1900s to the first half of the 1950s)

The major industries of this period were charcoal production and horse production. Charcoal production was a side job for most farmers. Generally, they produced charcoal only in the farmers' off-season, although some of them produced it throughout the year. Charcoal producers built rough lodges in the forest and moved there in the winter season for charcoal production (Hanawa-machi 1986). In this region, private forest accounted for only 23% of the forest area and most of the private forests were small. Therefore, the role of the national forest was important for forest resource uses. The local forestry office established custodial forest for the purpose of mowing for agriculture or for charcoal production, and made it available to the neighboring villages (Tokyo Regional Forest Office 1925). Horse production was one of the main industries. At that time, villagers accessed both national and private forests freely to use them as pasture and mowing sites. However, after the demarcation between the national and the private forest ownership, it became difficult for the villagers to use national forest freely for pasture and mowing (Hanawa-machi 1986).

Economic growth period (the latter half of the 1950s to the first half of the 1970s)

After the war, the traditional wood consumption patterns changed. Demand for pulpwood and construction timber increased with the growth of the Japanese economy, whereas fuelwood and charcoal production gradually decreased due to the energy revolution. Government promoted expansive afforestation with conifer plantations, which led to deciduous forests being cut down and converted to conifer production. Villagers were engaged in labor for site preparation, tree planting, and brushing in the national forest (Forest Agency 1964). Villagers used to collect grass, fallen leaves and twigs in common lands and forests. As tree planting in the grasslands gradually accelerated, the amount of available grass decreased. Up to the first half of the 1960s, horse production was converted to cattle production and utilization of grassland as pasture and mowing sites continued to decrease (Society of Sociology of Law of Ibaraki University 1956).

Stable growth period (after the first half of the 1970s)

During this period, the area of tree planting kept on decreasing. Forest resource uses in villages were continuously decreasing due to the decline of plantation activity in the national forest, and due to depopulation and aging of villagers.

Changes in land uses

Pre-war to reconstruction period (1900s to the first half of the 1950s)

Before this period (in 1908), the area was dominated by deciduous forest (70.5%) and grassland (27.3%), while there was no significant coniferous plantation in the study area (Fig.3, Table 1). Because the main industries were charcoal production and horse production, grasslands were utilized frequently as pasture and mowing, and the majority of grasslands were located close to the village (Fig.3).

Grassland decreased to 20.2% in 1947, and the majority of the decrease was replaced by deciduous forest and coniferous plantation during this period (Fig.3). Coniferous plantation emerged as a landscape element and accounted for 18.1% of the total area (Table 1).

Table 1 Changes in proportion of land use from 1908 to 1997

	1908	1947	1962	1975	1997
Coniferous plantation	0	18.1	28.1	46.2	48.4
Broad-leaved forest	70.5	64.0	58.6	35.9	32.9
Grassland	27.3	7.1	1.9	6.3	3.7
Others	2.3	10.8	11.4	11.5	15.1

Economic growth period (the latter half of the 1950s to the first half of the 1970s)

During this period, grassland decreased to 1.9% by 1962 before increasing again to 6.3% in 1975 (Table 1). In this same period, deciduous forest decreased from 58.6% in 1962 to 35.9% in 1975 (Table1). In contrast, coniferous plantation increased gradually, and it occupied approximately half of the study area (46.2%) in 1975 (Table 1). Coniferous plantation replaced deciduous forest, and became the most abundant landscape element in the study area.

Stable growth period (after the first half of the 1970s)

The areas of deciduous forest and coniferous plantation remained largely stable relative to the areas in 1975 (Table 1). However, many small narrow patches of deciduous forest appeared in the coniferous plantations (Fig.3).

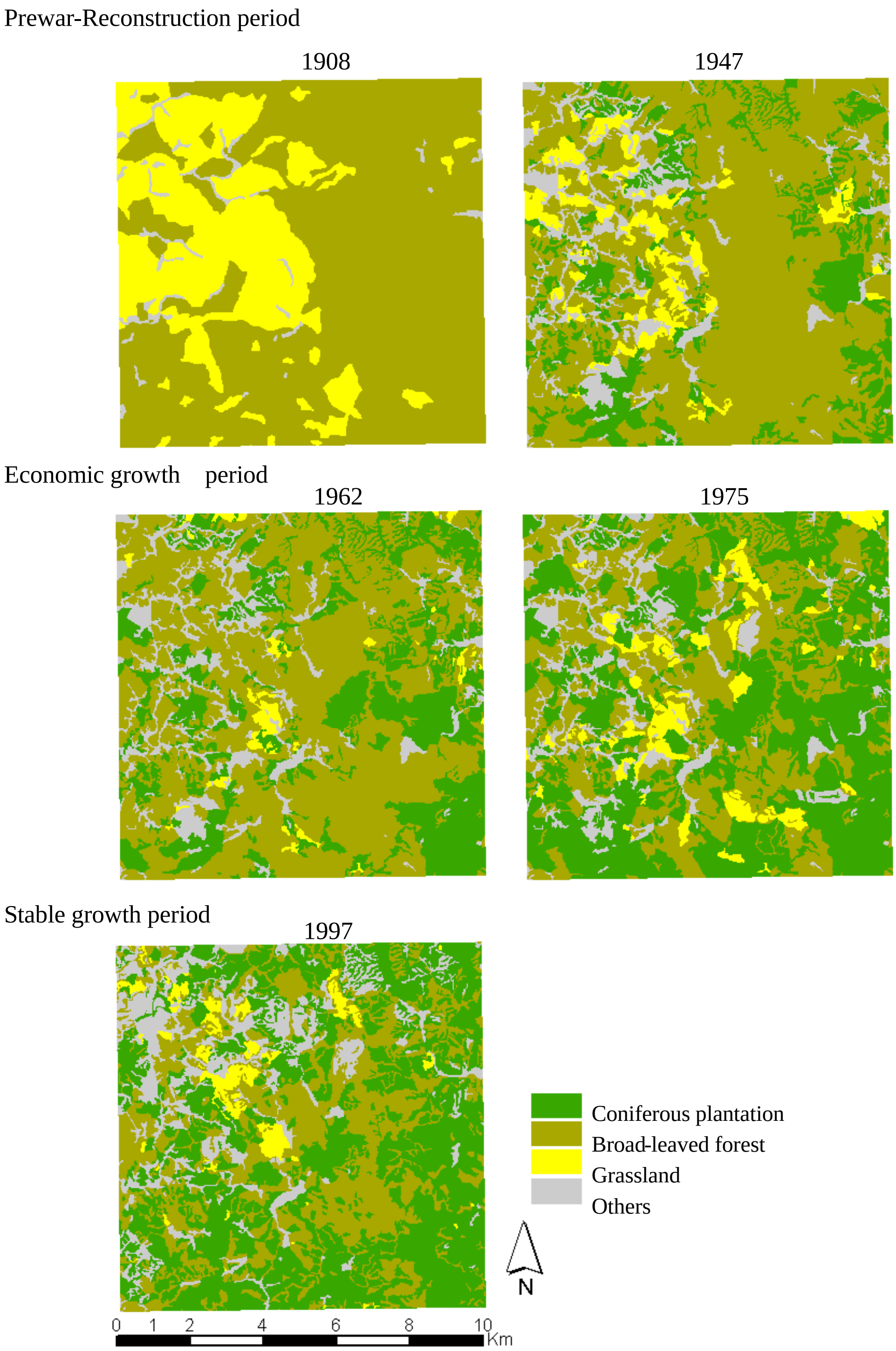

Fig.3 Land use change from 1908 to 1997

Discussion

The pattern of forest resource use changed drastically over the 20th Century, with the history of resource use being divisible into three periods (Fig.2) that paralleled the stage of economic growth. The landscape also changed along with these changes in forest resource uses. Before the war a lot of grasslands remained in the study area. However, most of the grasslands were replaced by deciduous forests or coniferous plantations. These changes seem to be caused by the prohibition of burning in national forests in 1929, the cessation of management of mowing sites due to labor shortages during the war, and the planting of conifer trees in grasslands (Tokyo Regional Forest Office 1947). In the economic growth period, the Forest Agency promoted expansive afforestation to supply the increasing demand for wood and to meet changes in fuel demand. The changes in the landscape of the study area clearly reflected these changes. Furthermore, the decrease of grassland in 1962 may have been caused by the introduction of chemical fertilizer instead of grass mowing, the growth in demand for beef, and the decline in the use of horses due to improvements in agricultural machinery and changes in the industrial structure. As a result of these driving forces, the use of grasslands as mowing sites and pasture declined drastically. In 1975, the area of grasslands increased a little (Table 1). In those days, the grasslands were abandoned, although parts of them remained, being improved from semi-natural grasslands to artificial grasslands for cattle, and new artificial grasslands were established. These grasslands and cut-over lands were included in the grasslands category of 1975, and the usage and the content of grasslands were completely different from the previous period. In the stable period, the total area of secondary forest patches remained almost stable from 1975 to 1997 (Fig.4), but many small, narrow secondary forest patches emerged in coniferous plantations (Fig.3). While logging proceeded in secondary forests, some plantation areas were abandoned due to labor shortages and an aging farming population, and those areas were replaced by secondary forests. Narrow patches must also have been kept as buffer strips to protect cut-over land and preserve scenic beauty under the "New forest management in the national forest" in 1973.

In the study area, many deciduous forests and grasslands had been kept for long periods of time because deciduous forest was an important resource for producing charcoal (coppiced every 20-30 years), and grassland was needed as mowing sites and pastures. However, the deciduous forests and the grasslands became fragmented or disappeared with the changes in forest resource uses. As a result, the landscape has drastically changed. Such modification and the loss of landscape elements mean the modification and loss of natural habitat for wildlife. In coppice forest of the Kanto district, clear relationships have been found between fragmentation of woodlands and the decrease of rare species and forest floor plants (Iida and Nakashizuka 1995). Loss of biota and biodiversity is feared as a result of stopping the cyclic use of forest resources in rural areas (Okubo et al. 2000; Kamihogi 2002). Maintaining or reconstructing suitable forest environments may be effective methods for preserving flora and fauna maintained in relation to traditional land use. However, this would require an enormous expenditure of effort and time. Therefore, as suggested by Inoue (2003), consideration should be given to effective methods to create an alternative environment through variations on current forest operation, such as rotated logging operation, which provides alternative habitats for wildlife as a substitute for those provided by traditional forest operation (coppicing) and grass mowing.

In this study, we were able to show the close relationships between the changes in society and human activities and forest landscape. Quantification of the land use and landscape history may contribute to the development of biodiversity research in fields such as biodiversity change at the regional scale, the contribution of landscape structure to regional biodiversity, the influence of fragmentation on biodiversity, and the prediction of future biodiversity in association with change of land use.

Acknowledgments This research was partly supported by the Research Institute for Humanity and Nature of Japan's Ministry of Education, Culture, Sports, Science and Technology (Project P2-2). We thank the Samegawa town office and the Tabito branch office of Iwaki city hall, and the people of Ogawa for offering their useful information. We also thank Mr. Yamagata Hajime for supporting the interview survey.

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Comparison of Transition Matrices of Land-use Dynamics in Two Research Sites

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Introduction

Several international research projects on the intensity of land use change have been started since the late 1980's, e.g. the Land Use and Cover Change program (Messerli, 1997) of International Geosphere-Biosphere Project (1988). These studies indicated the necessity of intensive studies on land-use changes, their speed and their driving forces. Developments all over the country cause the loss of a significant amount of agriculture land and natural forest. Local land-use and land-cover change can influence environmental and ecological changes. Two research sites we selected, Lambir National Park (Malaysia) and Deramakot Forest Reserve (Malaysia), have also been affected by the influence over 50 years, and the historical, social and ecological reasons would be very different depending on the locality and periods. To identify those reasons, quantitative research is necessary on the speed and the driving forces of their changes. As the first step to examine them, we here tried employing a mathematical model approach using transition matrix models.

Transition matrix model is a useful tool to analyze the characteristics of the land-use change and to forecast future dynamics and is easily constructed from area-based transition tables among land-use classifications. Popular GIS software, e.g. ARCGIS and RAMASGIS, supports a command to calculate the area-based transition tables from satellite images and aerial photographs. Therefore, many authors employed transition matrix models in these fifteen years (Ehlers et al., 1990; Meyer 1991; Hathout, 2002; Ademola, 2004).

We, in the present paper, quantified area-based transition tables and transition matrices of land-use in two research sites in order to grasp historical change of transition probabilities among census periods. To evaluate the historical change of transition probabilities properly, they should be compared under the same census interval. Unfortunately, satellite images or photographs of the research site in question are not always prepared every year or by a constant time interval in the specific research site. It's necessary to adjust the difference of census intervals of transition matrices mathematically. Therefore, we developed a formula of obtaining the yearly (annual) transition matrix to compare them among census periods. Using the formula, two yearly matrices in the research sites were obtained and the ten-year matrices were also calculated.

Methods

(i) Area-based transition tables and transition matrices of land use

We can quantify the type, amount and location of land use change in satellite images and aerial photographs, and some GIS computer programs provide a procedure to classify the land use and land cover, and to calculate the transition in the areas of the classifications of land use. We have three aerial photographs (of 1963, 1977 and 1997; Table 1a and 1b) in a part of Lambir National Park, Malaysia (about 275 square kilo-meters) and only two satellite images (of 1985 and 2002; Table 1c) in a part of Deramakot Forest Reserve, Malaysia (about 3500 square kilo-meters). Therefore, we calculated the area-based transition tables from those satellite images and aerial photographs of two research sites, and obtained 3 area-based transition tables in all (Table 1).

Probability-based transition tables, i.e. transition matrices, were also obtained from Table 1 (Table 2) because they are very convenient in comparing among research sites with different sizes and in calculating the dynamical projection of classifications of land use as:

$$\mathbf{x}_{t+c} = \mathbf{A}\mathbf{x}_t \quad , \qquad (1)$$

where $\mathbf{x}_t$, $\mathbf{A}$ and c represent the area vector at a census each of whose elements is the area of each classification, a transition matrix in question and the census interval, respectively. "$t+c$" in equation (1) generally means the next census. Unfortunately, the census intervals in Table 2 ranged from 14 to 20 years because of the lack of satellite images or aerial photographs. It implies that these obtained matrices cannot be compared directly because the transition probability during 14 years would be actually different from that during 20 years even if they are the same.

(ii) Formula of yearly transition matrix

The discrepancy of census periods in transition matrices does not allow us to evaluate two of them directly. Therefore, the normalization of census periods is necessary, that is, to obtain yearly transition matrix in every census period, which means the *c*-th power root of an original transition matrix, where *c* is census interval of the matrix. We developed a theorem on the *c*-th power root of a matrix and obtained the formula and the number of the solutions:

Theorem If a *n* by *n* matrix has *n* distinct eigenvalues and all of them are not equal to zero, the *c*-th power root of the matrix is:

$$\mathbf{A}^{\frac{1}{c}} = \begin{pmatrix} \mathbf{u_1} & \cdots & \mathbf{u}_n \end{pmatrix} \begin{pmatrix} (\lambda_1)^{1/c} & & 0 \\ & \ddots & \\ 0 & & (\lambda_n)^{1/c} \end{pmatrix} \begin{pmatrix} \mathbf{u_1} & \cdots & \mathbf{u}_n \end{pmatrix}^{-1} \quad , \qquad (2)$$

where $\mathbf{A}$, λ_i and $\mathbf{u}_i$ are a transition matrix with census interval of *c* years, the *i*-th eigenvalue of matrix $\mathbf{A}$ and its corresponding eigenvector, respectively.

Table 1 Area-based transition tables among land use classifications.

The numerics in cells represents the area of transition from a classification to another (ha).

(a) From 1963 to 77 in Lambir National Park. The total area is about 275 square kilo-meters

	1963				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland	230.2	683.3	588.1	0	0
Secondary Forest	724.9	3,027.4	2,016.9	0	0
Natural Forest	1.7	4.2	14,226.0	0	0
Selectively logged forest	0.0	108.6	4,222.4	0	0
Plantation	0.0	130.6	1,446.0	0	0
Total	956.8	3,954.1	22,499.4	0.0	0.0

(b) From 1977 to 97 in Lambir National Park. The total area is about 275 square kilo-meters

	1977				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland	245.2	211.3	2.2	5.8	0.0
Secondary Forest	1,253.5	5,517.8	888.9	1,965.7	1,524.8
Natural Forest	0.0	6.7	6,364.5	0.0	0.0
Selectively logged forest	0.3	11.6	6,524.2	2,356.8	0.0
Plantation	0.0	13.4	556.3	0.0	51.8
Total	1,499.0	5,760.8	14,336.1	4,328.3	1,576.6

(c) From 1985 to 2002 in Deramakot Forest Reserve.

The total area is about 3500 square kilo-meters.

	1985				
	Cropland	Secondary Forest	Natural Forest	Selectively logged forest	Water
Cropland	41370.6	2259.3	49166.2	35269.8	777.5
Secondary Forest	563.2	45.8	549.7	146.5	3.3
Natural Forest	6189.9	1855.0	40801.9	19146.1	86.1
Selectively logged forest	17560.2	1558.2	50514.1	77961.3	162.4
Water	422.3	136.4	30.0	103.1	886.0
Total	66106.3	5854.7	141061.8	132626.8	1915.3

Table 2　Transition matrices among land use classifications.

The numerics in cells represents the transition prpbability from a classification to another.

(a) From 1963 to 77 in Lambir National Park.

	1963				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland	0.241	0.173	0.026	0	0
Secondary Forest	0.758	0.766	0.090	0	0
Natural Forest	0.002	0.001	0.632	0	0
Selectively logged forest	0.000	0.027	0.188	0	0
Plantation	0.000	0.033	0.064	0	0

(b) From 1977 to 97 in Lambir National Park.

	1977				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland	0.164	0.037	0.000	0.001	0.000
Secondary Forest	0.836	0.958	0.062	0.454	0.967
Natural Forest	0.000	0.001	0.444	0.000	0.000
Selectively logged forest	0.000	0.002	0.455	0.545	0.000
Plantation	0.000	0.002	0.039	0.000	0.033

(c) Deramakot Forest Reserve in Malaysia.

	1985				
	Cropland	Secondary Forest	Natural Forest	Selectively logged forest	Water
Cropland	0.626	0.386	0.349	0.266	0.406
Secondary Forest	0.009	0.008	0.004	0.001	0.002
Natural Forest	0.094	0.317	0.289	0.144	0.045
Selectively logged forest	0.266	0.266	0.358	0.588	0.085
Water	0.006	0.023	0.000	0.001	0.463

Collorary　If a n by n matrix has n distinct eigenvalues and all of them are not equal to zero, the number of the c-th power root of the matrix is c^n.

<The proof is abbreviated>

$(\lambda_i)^{1/c}$ means the c-th power root of the scalar λ_i. Since λ_i could be a complex number, we may set

$\lambda_i = re^{i\theta} = r(\cos\theta + i\sin\theta)$ ($r > 0$ and $0 \le \theta < 2\pi$), using polar coordinates. Therefore, $(\lambda_i)^{1/c} = r^{1/c}(\cos\frac{\theta + 2\pi k}{c} + i\sin\frac{\theta + 2\pi k}{c})$ for $k = 0,1,\ldots c-1$ and generally has c solutions including complex numbers, which is why the number of the solutions are c^n .

We also developed computer programs of Mathematica (Wolfrum Research, Inc.) and C++ to calculate equation (2) and to obtain all of c^n solutions at the same time. It is opened on the website, http://hosho.ees.hokudai.ac.jp/~takada/eindex.html. The program by C++ is about 800 times faster than that by Mathematica.

Result

(i) Quantification of land use change

The quantification of land use change for the analyzed classifications are given in Table 1 and 2. The former is an area-based table and the latter is a probability-based table, i.e. transition matrix. "Natural forest" was the largest class in Lambir and Deramakot of Malaysia (Table 1a, 1b and 1c). The speed of land use change cannot be compared using the area-based tables because their total areas are different among two research sites, and cannot be compared using the probability-based tables because their census periods varied largely. We refer to the comparison of the speeds in land use change later, when we obtain the yearly transition matrices and ten-year transition matrices.

(ii) Yearly transition matrix and several problems

Yearly matrix has plural solutions and, for example, the yearly matrix in Lambir Park during 1977 and 1997, has 20^5 (= 3,200,000) solutions, elements of which could include negative and complex numbers, as explained in Method. The elements of a correct yearly matrix should range from 0 to 1 because those elements are probabilities. Therefore, we should omit solutions with negative or complex numbers after the calculation. The computer program is actually made to omit matrices with large negative real parts or imaginary parts, taking into account of rounding errors in numerical calculation.

At the second stage (1977-97) in Lambir National Park, we unfortunately obtained no positive solution. A solution among 20^5 solutions includes only one negative element whose absolute value is very small (Table 3b), and all of the other solutions include elements smaller than minus 0.5 and/or complex numbers. We think the former is the appropriate solution and its negative elements might be brought from rounding errors in numerical calculation or the failure of image analysis in land use classification. In Deramakot (Table 3c), we similarly have single appropriate solution among about a million solutions. In Lambir National Park (Table 3a), we couldn't obtain the yearly transition matrix at the first stage, using equation (2), because the transition matrix during 1963-77 in Table 2a has two zero eigenvalues

Most of diagonal elements of yearly transition matrices are larger than 90% and the land-use changes in all the research sites is very slow by yearly rate. We calculated the ten-year matrices (10-th power matrices of yearly ones) in all the sites to understand the speed of land-use change intuitively (Table 4).

Table 3 Yearly transition matrices. .

(a) From 1963 to 77 in Lambir National Park. We couldn't obtain the matrix at the first stage

	1963				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland					
Secondary Forest					
Natural Forest			NONE		
Selectively logged forest					
Plantation					

(b) From 1977 to 97 in Lambir National Park. Though the matrix includes negatibe element, it is only appropriate solution among 20^5 solutions.

	1977				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland	0.906	0.004	0.002	−0.002	−0.020
Secondary Forest	0.095	0.995	−0.019	0.032	0.180
Natural Forest	0.000	0.000	0.960	0.000	0.000
Selectively logged forest	0.000	0.000	0.045	0.970	0.000
Plantation	−0.001	0.000	0.011	0.000	0.840

(c) Deramakot Forest Reserve in Malaysia. Though the matrix includes negatibe element, it is only appropriate solution among 17^5 solutions.

	1985				
	Cropland	Secondary Forest	Natural Forest	Selectively logged forest	Water
Cropland	0.965	0.052	0.041	0.022	0.043
Secondary Forest	0.004	0.712	0.001	−0.001	−0.002
Natural Forest	0.006	0.251	0.915	0.021	0.004
Selectively logged forest	0.025	−0.026	0.045	0.958	−0.001
Water	0.001	0.012	0.000	0.000	0.955

Table 4 Ten-year transition matrices in three research sites.

(a) From 1963 nto 77 in Lambir National Park. We couldn't obtain the matrix at the first stage,

	1963				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland					
Secondary Forest					
Natural Forest			NONE		
Selectively logged forest					
Plantation					

(b) From 1977 nto 97 in Lambir National Park. The elements in matrices are sometimes negative.

	1977				
	Cropland	Secondary Forest	Natural forest	Selectively logged forest	Plantation
Cropland	0.383	0.027	0.005	−0.005	−0.042
Secondary Forest	0.620	0.969	−0.042	0.268	0.868
Natural Forest	0.000	0.001	0.666	0.000	−0.001
Selectively logged forest	0.000	0.001	0.324	0.738	−0.001
Plantation	−0.002	0.002	0.046	−0.001	0.176

(c) Deramakot Forest Reserve in Malaysia. The elements in matrices are sometimes negative.

	1985				
	Cropland	Secondary Forest	Natural Forest	Selectively logged forest	Water
Cropland	0.635	0.029	−0.001	0.000	0.005
Secondary Forest	−0.001	0.037	0.003	−0.001	0.010
Natural Forest	0.027	0.482	0.445	0.120	0.064
Selectively logged forest	0.033	0.141	0.284	0.698	0.189
Water	0.306	0.311	0.269	0.182	0.733

Discussion

In examining the land use change in terms of satellite images or aerial photographs, we often don't have enough number of photographs and cannot construct transition matrices with constant census intervals. We here developed a way to calculate the yearly transition matrix from a transition matrix with long census period. This way would be useful when we want to compare among transition matrices with different census intervals, as shown in Table 3 and 4. While we applied the formula for yearly transition matrix to three transition matrices in two research sites (Table 2), we are confronted with two difficulties. One is that no positive matrix is obtained in all the cases. From our experience, small negative elements in yearly transition matrices are likely to occur when many zero or small elements are included in the original matrix. For example, in Deramakot, there are 9 elements under 0.01 among 5x5 elements (Table 2c). Since the transition among classification is usually slow in forest ecosystems, there might be many small elements in the original matrix. Then, we would obtain a yearly transition matrix with negative elements close to zero, and those negative elements could be assumed to be approximately zero. It would be derived from rounding errors in numerical calculation.

In the yearly transition matrix of Lambir National Park, there were large negative values in Table 3e, i.e. the transition probability from “plantation” to “cropland” and that from “natural forest” to “secondary forest”. It’s difficult to think those negative values are derived from rounding errors in numerical calculation. One of the possibilities is that GIS software made a mistake in the classification of land use and improbable transition was picked up from photographs. It is also probable that the drastic change of land use occurred during the census period and it is not adequate to calculate the average transition rate (yearly transition matrix). We have not identified the causes yet.

The other difficulty is that we couldn’t obtain the yearly transition matrix at the first stage in Lambir National Park (Table 3a), Mathematically speaking, the reason is why two of the eigenvalues of the original transition matrix are zero and equation (2) could not be applied to the matrix. It also means that ”selectively logged forest” and “Plantation” of the land use classification newly appeared in 1977. The appearance of new land-use classification could occur occasionally where human activity is strong. Therefore, a question remains unsolved, how to obtain yearly transition matrix where there are zero eigenvalues of the original matrix.

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